DOCUMENT RESUME

ED 385 997 EC 304 199

AUTHOR Presperin, Jessica J., Ed.
TITLE Technology for the Nineties. RESNA '91: Proceedings of the Annual Conference (14th, Kansas City, Missouri, June 21-26, 1991).
INSTITUTION RESNA: Association for the Advancement of Rehabilitation Technology, Washington, DC.
REPORT NO ISBN-0-932101-29-1; ISSN-0883-4741
PUB DATE 91
NOTE 456p.
AVAILABLE FROM RESNA Press, 1101 Connecticut Ave., N.W., Suite 700, Washington, DC 20036.
PUB TYPE Books (010) -- Collected Works - Conference Proceedings (021)

EDRS PRICE MF01/PC19 Plus Postage.
DESCRIPTORS Accessibility (for Disabled); *Assistive Devices (for Disabled); Clinical Diagnosis; Communication Aids (for Disabled); Computer Oriented Programs; Delivery Systems; *Disabilities; Electronic Equipment; Elementary Secondary Education; Evaluation Methods; Gerontology; Information Dissemination; Input Output Devices; Language Processing; Medical Services; Mobility Aids; *Physical Disabilities; Physical Mobility; *Rehabilitation; Robotics; Rural Areas; Sensory Aids; Special Education; *Technological Advancement; Technology Transfer
IDENTIFIERS Speech Technology

ABSTRACT

This proceedings document contains approximately 150 papers and 50 poster sessions presented at a conference on the advancement of rehabilitation and assistive technology. Individual sessions focused on the following topics: gerontology, robotics, technology transfer, sensory aids, computer applications, information dissemination, service delivery models, language processing, quantitative assessment, mobility and seating, rural settings, design issues, special education, clinical issues, functional electrical stimulation, job accommodations, and speech technology. Poster sessions dealt with mobility and seating, augmentative and alternative communication and functional electrical stimulation, service delivery, and technology transfer. Additionally, the five winning papers of the Easter Seal student design competition are included. Proceedings papers typically include an abstract, text, illustrations or graphs, address of the principal investigator, and references. (DB)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED 385 997

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

☑ This document has been reproduced as received from the person or organization originating it.

☐ Minor changes have been made to improve reproduction quality.

- Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

RESNA '91

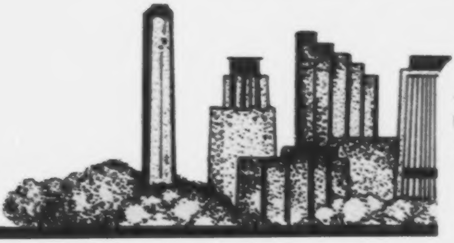
Technology for the Nineties

◆

PROCEEDINGS of the 14th Annual Conference

◆

Allis Plaza Hotel
Kansas City, Missouri
June 21-26, 1991



"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

I. Kramer

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

EC 304199

BEST COPY AVAILABLE

RESNA '91

PROCEEDINGS of the 14th Annual Conference

Technology for the Nineties

June 21-26, 1991

Allis Plaza Hotel
H. Roe Bartle Hall
Kansas City, Missouri

Jessica J. Presperin, OTR/L, MBA
Editor

M.A. Medhat, M.D., Ph.D.
Conference Chair

RESNA PRESS

Proceedings of the RESNA 14th Annual Conference
Kansas City, Missouri
June 21-26, 1991

Volume 11
ISSN 0883-4741
ISBN 0-932101-29-1

Copyright © 1991
RESNA

All rights reserved. This book or any part thereof may not
be reproduced in any form without the permission of the publisher.

RESNAPRESS

1101 Connecticut Avenue, N.W., Suite 700
Washington, D.C. 20036, (202) 857-1199

Printed in the United States of America
Dependable Printing Company, Inc.

Foreword

RESNA, a leader in advancing the field of rehabilitation and assistive technologies, has been a strong advocate of progressive legislation on behalf of persons with disabilities. RESNA played a key role in the development of the Technology-Related Assistance for Individuals with Disabilities Act of 1988 and the Americans with Disabilities Act (ADA), signed into law on July 26, 1990. RESNA has been actively involved in implementing this first piece of legislation through its technical assistance contract with the NIDRR.

RESNA now has an important leadership role to play in making assistive technology a major force behind the full implementation of the ADA. This can best be accomplished in the long term by evolving education, quality assurance and credentialing programs, and by developing improved means for service providers and consumers to access assistive technology information. This is certainly a significant way that RESNA can serve its members so they, in turn, can serve those in need of increased access through technology.

RESNA's 14th Annual Conference in Kansas City, America's Heartland, is our first major meeting since the enactment of the ADA. It provides an excellent forum to discuss issues and formulate directions which can affect the lives of persons with disabilities for years to come.

As in past years, our Annual Conference once again creates an opportunity to revitalize our commitment, share ideas, renew old acquaintances and add names to new faces. We sincerely wish that RESNA '91 fulfills all these expectations and many more.

We extend our warmest welcome to the participants in this RESNA conference and our deepest appreciation to all of those who have helped to make this another successful RESNA event. Work, enjoy, return home safely and plan on being with us next year in Toronto.

Mohamed Medhat, M.D.
Conference Chair

Douglas A. Hobson, Ph.D.
President

Preface

Kansas City, the land of OZ, and one of the heartland cities of the United States, beckons us to center ourselves on the technology of today, with a futuristic forum for following the yellow brick road to meeting the goals of tomorrow.

RESNA's Meetings Committee, chaired last year by Tony Langton and now by Don McNeal, volunteered its time to bring together this conference schedule of scientific sessions, morning seminars, instructional courses, multi-media events, student design competition, computer tech lab, and exhibits. These Proceedings are the result of this effort and afford you an opportunity to share in the plethora of rehabilitation and assistive technology information that characterizes this Annual Conference.

For this year's conference, the computer tech lab was upgraded with the help of Ken Kozole, Mary Binion, David Jaffe, Bob Smallwood, Marian Hall, and Susan Leone. This new prospective format allows for exchange of software information and computer instruction.

The addition of Special Education and Job Accommodations SIGs broadened RESNA's membership and the pool of conference participants to include professionals from the education and vocational rehabilitation sectors, who may not have previously been involved with RESNA. Although activity in this area has been going on for quite some time, the formation of these SIGs allows for the formalized exchange of information in these specialized areas.

I would like to thank the SIGs for their efforts in reviewing the scientific papers, organizing instructional courses and morning seminars, and putting together special sessions. Their work is obvious when noting all that is offered during the conference.

I also would like to recognize the efforts of Dr. Mohamed Medhat and the Local Committee who worked hard to add local flavor to this 14th Annual Conference, as well as assure accessible transportation and lodging. Thanks to them, we enjoyed a HEARTLAND of entertainment including a delicious KC barbeque and professional baseball game!

Most of all, I would like to thank Susan Leone of the RESNA staff for her meticulous skill in pulling together all the work of the Meetings Committee, SIGs, and other conference participants, and in organizing this 14th Annual Conference to be such a success.

Jessica J Presperin, OTR/L MBA
Chair, Scientific Program
& Special Interest Group Committee

Conference Organizing Committee

Conference Chairs
MA Medhat, MD, Professor Rehab Med, Kansas University Medical Center
John H Leslie, PhD, Cerebral Palsy Research
Meetings Committee Chair
Donald R McNeal, PhD, Rancho REC
Scientific Program
Jessica J Presperin, OTR/L MBA, Sharp Rehab Ctr
Instructional Program
Susan Johnson Taylor, OTR/L, American Rehab
Exhibits
Mary Binion, MA, Ohio Resource Ctr
Accessibility
Anthony J Langton, MS, So Carolina Voc Rehab
Student Design Competition,
Computer Theatre, & Multi-Media Theatre
Ken Kozole, BSME OTR, Sharp Rehab Ctr
Regional Conferences Liaison
Katherine M Post, MS OTR/L, Newington Children's Hosp
Local Arrangements Committee
Leonard Anderson, MS, Cerebral Palsy Research
Philip Cacioppo, PE, Kansas City, MO
Cheryl Carpenter, CPTA, KC Physical Therapy Group
Randall Chambers, PhD, Wichita St Univ
Judy Cotton, MA, Cerebral Palsy Research
Paul Denning, Cerebral Palsy Research
Cheryl Detrding, OTR, Kansas Univ Med Ctr
Jeffrey Fernandez, PhD, Wichita St Univ
Bobbi Greenwood Arp, PT, Mid America Rehab Hosp
Elmer Hoyer, PhD, Wichita St Univ
Everett Johnson, PhD, Wichita St Univ
Winifred Jones, MA Ed, Cerebral Palsy Research
Steve Mallernee, Cerebral Palsy Research
Don Malzahn, PhD, Wichita St Univ
Sue Merryfield, OTR, Kansas Univ Med Ctr
Roy Norris, PhD, Wichita St Univ
Leah Ross, MEd, Cerebral Palsy Research
Susan Scholl, PT, Cerebral Palsy Research
Jodi Stensrud, Cerebral Palsy Research
Patrick Terick, Cerebral Palsy Research
Paul Trautman, CPO, Ortho Svcs Inc
Conference Management
Dennis E. Smeage, Executive Director
Susan P. Leone, Meetings Director
Cele Fogarty, Convention Coordinator
Francine Garner, Registrar

RESNA Board of Directors

Executive Committee
President
Douglas A Hobson, PhD, Canadian Aging & Rehabilitation Product Development Corporation
President Elect
Gregg C Vanderheiden, PhD, Trace R&D Center
Secretary
Carol H Gwin, BS OTR, American Occupational Therapy Association
Treasurer
Clifford E Brubaker, PhD, University of Virginia REC
At Large Members
Jan C Galvin, National Rehabilitation Hospital
Jan Little, MS, UCPA Chicago
Immediate Past President
Richard A Foulds, PhD, AI duPont Institute

Board of Directors
Peter W Axelson, MSME, Beneficial Designs Inc
Albert M Cook, PhD PE, California State University
Alexandra Enders, OTR, University of Montana RTC Rural
Paul N Hale Jr, PhD PE, Louisiana Tech University REC
David L Jaffe, MSE, Palo Alto VAMC Rehabilitation R&D Center
Ken Kozole, BSME OTR, Sharp Rehabilitation Center
Anthony J Langton, MS, South Carolina Vocational Rehabilitation
Katherine M Post, MS OTR/L, Newington Children's Hospital
Barry A Romich, BSE PE, Prentke Romich Company
Sheldon R Simon, MD, Ohio State University
Elaine Trefler, OTR Med FAOTA, Winnipeg, Canada
Gerald Weisman, MS, Vermont REC
Jody J Whitmyer, Whitmyer Biomechanix Inc

Past Presidents
C Gerald Warren, MPA, C Gerald Warren & Associates
Sheldon R Simon, MD, Ohio State University
Dudley S Childress, PhD, Northwestern University
Morris Milner, PhD PEng CCE, Hugh MacMillan Rehabilitation Centre
Donald R McNeal, PhD, Rancho Los Amigos REC
Colin A McLaurin, ScD, University of Virginia REC
James B Reswick, ScD, National Institute on Disability & Rehabilitation Research

RESNA Gratefully

...acknowledges conference support from the following PATRONS

IBM National Support Center
  for Persons with Disabilities
National Easter Seal Society
Adaptive Communication Systems
Medical Equipment Distributors
Apple Computers, Inc
  Office of Special Education
Everest & Jennings, Inc
Cerebral Palsy Research Foundation of Kansas
Jay Medical
Saint Joseph Health Center
First National Bank of Wichita
U.S. Department of Veterans Affairs
  Vocational Rehabilitation & Counseling Division
Prentke Romich Company
Semantic Compaction Systems
Hear Our Voices

...recognizes the assistance of the following organizations

Advacare Medical Equipment
American Rehab
Carondelet Health Corporation
Hugh MacMillan Rehabilitation Centre
Kansas City Physical Therapy Group
Kansas University Medical Center
Mid America Rehabilitation Hospital
Newington Children's Hospital
Ohio Resource Center for Low Incidence & Severely Handicapped
Orthopedic Service, Inc
Rancho Los Amigos Medical Center
Sharp Rehabilitation Center
South Carolina Vocational Rehabilitation Department
Wichita State University

Table of Contents

Session 1 Gerontology

Upper body motion and balance stability in the elderly 1
Assistive devices and the elderly: a shotgun wedding? 4
Walker performance evaluation by a panel of older walker users 7

Session 2 Robotics

Mobile robotic platform capable of following a human companion 10
Interactive robotics: applications in manufacturing industry 13
Factors in the prescription and cost effectiveness of robot systems for high-level quadriplegics 16
Low cost pneumatic actuators for applications in rehabilitation robotics 19
Further development of a robot workstation for the disabled 21

Session 3 Technology Transfer

From prototype to commercial product in Sweden 23
A follow-up plan for rehabilitation technology: an occupational therapist's role 24
Management of spasticity via electrically operated force reflecting sticks 27
A case study of using disk medial to disseminate bibliographic information 28
An interdisciplinary approach to product assessment 30
Technology transfer through student design projects 33
Using the knowledge of human factors engineering in rehabilitation services 36

Session 4 Sensory Aids

Intelligibility experiments with a feature extraction system designed to simulate a low-bandwidth video telephone for deaf people 38
ASCII-based TDD products: features and compatibility 41
Evaluation of liquid crystal display panels for presenting real-time speech-to-text to persons with acquired deafness 44
The importance of user interface and interaction design 46

Session 5 Computer Applications

Voice and head pointer operated electronics computer assisted design workstation for individuals with severe upper extremity impairments 48
EMG activated switch for control of computer functions by persons with quadriplegia 50
A programmable scanning keyboard for the IBM PC 53
A model for designing an alternative access system for the Macintosh 55
The control interface assessment system: a computerized assessment tool to evaluate control interface devices 58
Improving alternative access to computer games 61
The universal access system and disabled computer user 64

Session 6 Information Dissemination

Training therapists in technology: barriers and solutions for the third year of the TechSpec Program 67
Development and operation of a national information dissemination program: one REC's experience 70
Technology training: resources for the trainer 72
MSDOS-ABLDATA: an MS-DOS and screen reader compatible program for retrieving information from ABLEDATA 74

Session 7 Service Delivery Models

Utilizing technology in the vocational rehabilitation process 76
Cooperative service delivery: a cost-effective strategy 79
Development of a model rehabilitation engineering program 82
A comprehensive rehabilitation technology service delivery model utilizing speech recognition technology 85
A model for assessing the needs of disabled employees in the work place 88
Techworks rehabilitation engineering services in New Mexico--two years later 90
Collaboration: a partnership for providing assistive technology services in Michigan 92

Session 8 Language Processing

The function of function words and function units in augmentative communication 94
Automatic abbreviation generation 97
The effectiveness of word prediction 100
Speller: an alternative spelling correction system 103
Syntax PAL - a system to improve the syntax of those with language dysfunction 105
Predictive retrieval of conversational narratives in an augmentative communication system 107
Knowledge representation considerations for a domain independent semantic parser 109
Vocabulary selection for intelligent parsing in an AAC system for aphasics 112

Session 9 Quantitative Assessment

The effects of physical ability on the working memory requirements of computer input devices 115
An interactive tool for visualizing the biodynamics of human movement 118
Vertical vestibular stimulation and cerebral palsy--a preliminary report 121
A constraint for human arm motion in joint space 123
Identification of a low dimensional invariant function of lifting 125
Design of the patient interface for a computer-based tremor--characterization system 128
The Polhemus Isotrack as an assessment tool for cerebral palsy 131
Physical activity profiles: using the actimeter for vocational assessment 133

Session 10 Mobility and Seating

Power mobility: a parents view 136
The effect of transducer curvature on interface pressure readings 138
Development of an analog controller interface to relate steered front wheels to powered rear wheels 140
Antiskid wheelchair brake design 143
Improved wheelchair gearbox efficiency 146
An improved DC-DC converter for electric wheelchair propulsion 148
A new method for electric wheelchair propulsion 151
The development of an HMRC heavy duty joystick 154

Session 11 Computer Applications

Dynamic competition selection technique for computer access 157
WIVIK: a visual keyboard for windows 3.0 160
PRoviding computer access features under DOS 163
The use of integrated controls for mobility, communication and computer access 166
An alternative approach to computer access: the "Adam" interface for the Macintosh 168
Alternative writing devices for the inefficient writer 171
Direct multi-switch key selection 174
Preliminary studies for a simple personalized computer interface using voice/sound recognition to facilitate communication and environmental control for severely disabled dysarthric individuals 176

Session 12 Rural

Rural assistive technology services: the Montana adaptive equipment program 179
Agricultural worksite accessibility for farmers and ranchers with spinal cord injuries 181
Mobile rural assistive technology unit 183
Alternative agricultural enterprises for farmers with physical disabilities 185

Session 13 Service Delivery

Guidelines for the design of consumer products to increase their accessibility to persons with disabilities 187

Who is a rehabilitation engineering? 190

An internship program for the training of rehabilitation technologists 193

Use of a database system for providing demographic and outcome data in an assistive technology clinic 196

A survey of Tennessee DRS employees on assistive technology 199

PRT--a mass transit system with significant benefits for the disabled and elderly 202

Session 14 Design Issues

Using a social approach in the development of a communication aid to achieve perceived communicative competence 204

Enhancements to the semantic compaction paradigm for vocabulary organization 207

The design of a device independent screen class for augmentative communication software 210

An enhanced operating system for the Prentke Company Touch Talker and Light Talker 213

Miniaturizing AAC devices 216

Session 15 Special Education

Infants with disabilities and their families: a conceptual model for technology assessment 219

Adaptive equipment design for special education by interdisciplinary undergraduate students 222

Comprehensive training on assistive technology: a functional student-centered approach 225

Toward a switch-smart GUI 227

Centers of energy 230

Session 16 Mobility and Seating

Personalized power wheelchair for a cerebral-palsied adolescent 231

A user survey on backup power for powered wheelchairs 234

Structural reliability assessment techniques applied to tubular wheelchair frames 237

A derivation of turning geometry and turning dynamics for racing wheelchairs 240

Optimizing of a customized seating service 243

A comparison of pulmonary functions of wheelchair racers in their racing and standard wheelchairs 245

A second-generation joystick for people disabled by tremor 248

Safety aspects of a user control for a mobility device 251

Session 17 Clinical Issues

The effect of communication aid characteristics on the interaction skills of nonspeaking persons and their adult speaking partners 254

Age-related differences in interface control in normally developing children 257

Relationship of communication speed and rate to the perceived communicative competence of high school AAC users 260

Using Words Strategy to assess grammatical concepts 263

Development of motor skills for communication: a case study 266

Alternative communication for a severely disabled non-speaking Guillian Barre syndrome patient - a case study 269

Session 18 Functional Electrical Stimulation

Enhanced neovascularization of healing pressure sores with electrical stimulation 272

Spasticity in SCI: day-to-day variability in response to joint movement and electrical stimulation 274

Endogenous potentials of human skin injuries 277

Different modes of electrical stimulation for reduction of spasticity in CP children 280

Improved voluntary gait pattern post stroke, following treatment with the multi-channel, intramuscular, microprocessor-based FNS system 283

Efficiency of electrically stimulated exercise: normal vs SCI 286

Changes in recruitment curves of nerve helix electrodes with time following implantation and knee angle 289

Use of threshold current changes as an index of responsiveness and fatigability in paralyzed muscle during functional neuromuscular stimulation 292

Session 19 Job Accommodation

Training in rehabilitation engineering/technology 295
A training program for ambulatory adults with cerebral palsy that improves lifting capacity 298
A computer-controlled, wheelchair-guided boat for therapy and recreation 300
Foot operated hold down 303
One handed paper folder. 305
Technology and employment 306

Session 20 Speech Technology

Speech recognition to enhance computer access for children and young adults who are functionally nonspeaking 308
Emotional synthetic speech in an integrated communication prosthesis 311
Synthesized spanish speech using letter-to-sound rules 314
A strategy for gestural control of synthetic speech 317
The CANDY project: gesture-driven speech synthesis 320

Session 21 Computer Applications

From voice to sign language: a translation tool for the workplace 323
A modular software for controlling an optacon-computer interface 326
Towards a method for computer interface design using speech recognition 328
A user's perspective on blind access to graphical user interfaces 330
Hardware description of a portable electronic memory device 333
Prospects of automatic speech recognition and relay service 335
Software design guidelines for accessibility to a computerized case management system for speech based screen review systems used by people with blindness 338
The assistive dining device: a tool for mealtime independence 341

Poster Session 1
Mobility and Seating

A customized headrest for pressure relief and lateral support 344
Driver's education for power mobility: Part II 347
A cost-effective approach to extended assessment and preliminary training for powered wheelchair control 350
Small improvements in seating hardware 353
A new method to assess the dynamic rear stability of occupied wheelchairs 356
Custom molded seating at North Dakota's developmental center 358
Development of a protective helmet for persons with disabilities 361
Comparison of "Keane" and "Roto-Rest" kinetic beds 364
A vinyl vacuum forming processing for covering FIP systems 367
The customization of an arm slot controller - a case study 370

Poster Session 2
Augmentative & Alternative Communication

A better mount for light pointers 373
Adapting the "Hopkins Speaking Valve" for use with a shiley cannula 376
The future of augmentative communication: a conceptual framework for consumer empowerment -- a consumer's perspective 379
A remote-controlled communication device for simple clinical, classroom and home applications 381
Eyegaze and headpointing technology for children and adults with mental retardation 383
Your Expressive Society (YES) - an augmentative communication users support group 386

Functional Electrical Stimulation

The effect of electrical stimulation on healing rate in diabetic patients 388
Multichannel electrical stimulation system for gait assist and cyclical stimulation 391
Training tools for a neuroprosthetic hand system 394
Evaluation of the CASE multichannel FNS system for restoration of hand function in C5-C6 quadriplegics 397
FES exercise and disuse osteoporosis 399
Intraoperative tendon tension and wrist angle measurement system 402

Poster Session 3

Service Delivery

A twin size bed with features of a crib for use with the disabled 405
Lifting device for car trunk to prevent back injury 407

Personal Transportation

The development of a multi-function vehicular control interface unit for quadriplegic drivers 409

Poster Session 4

Technology Transfer

Calibration of implant pressure transmitter 411
Programmable interface box for switches 414
Development of bathtub with integral hydraulic seat lift 417
Mechanical adaptations to play electronic musical instruments for the promotion of exercise 420

Easter Seal Student Design Competition

Futura TDD: software for Baudot/ASCII translation modems 425
A power wheelchair soccer guard which is quick and easy to use 427
Therapeutic play environment for blind and visually impaired children 430
Tomorrow's chair: a device to facilitate sitting and standing 433
A portable, trunk-supporting toilet seat 436

UPPER BODY MOTION AND BALANCE STABILITY IN THE ELDERLY

Eric E. Sabelman, PhD *, Melissa G. Hoy, PhD *, Carol H. Winograd, MD †
Palo Alto VA Medical Center, * Rehabilitation R&D Center, and
†Geriatrics Research, Education and Clinical Center

ABSTRACT

Falls present a serious health hazard to elderly, post-surgical and partially-disabled ambulatory persons. Quantitative examination of relative body segment motion using self-contained data acquisition equipment can provide information valuable for preventing falls or minimizing resultant injury. This proposal is aimed toward development of a balance assessment and fall detection tool that relies on measurement of relative accelerations of the head and upper body, as distinct from gait and lower body studies. This approach permits identification of contributory factors such as visual distraction and emphasizes the body segments that contribute most to postural instability. Results of a pilot study demonstrate the ability to detect reduced stability during standing with eyes closed, and age-related characteristic head and trunk motions during rising from a chair and walking down stairs.

BACKGROUND

The ultimate goal of this project is to provide means for fall-prone individuals to live independently who might otherwise have to be institutionalized. We envision this to be a wearable accelerometric instrument – a "balance orthosis" – making it possible to record an individual's movements during everyday activities in a non-laboratory setting, identify patterns of movement that accompany loss of balance before a fall actually occurs, alert the individual of pre-fall behavior, and if necessary, signal a remote attendant that a fall has taken place. In the short term, we expect the instrument to be useful for a subset of the fall-prone population who have recognizable pre-fall motion patterns, and for improving clinical diagnosis of balance disorders.

Most balance assessment methods concentrate on the lower body and the relationship of the body's center of mass to the position of the feet [1]. However, control of orientation of the trunk with respect to gravity is a significant factor in maintaining balance [2]. Upper body accelerometry permits calculation of head and trunk rotational and translational velocities and head pointing direction, indicative of attention to direction of movement.

METHODS

Before clinical or in-home use, laboratory tests must be done to distinguish balance-related motion patterns from, for example, head movement normally associated with talking [3]. To develop the necessary algorithms for distinguishing harmless from pre-fall motions, we have been test subjects using elements of standard qualitative balance assessment protocols [4].

Fig. 1: A. ACCELEROMETRY COORDINATE SYSTEM

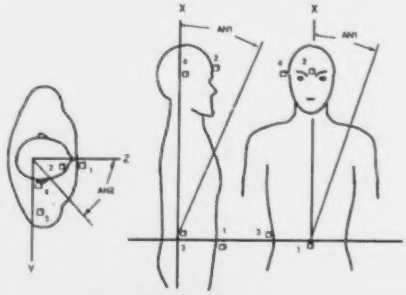
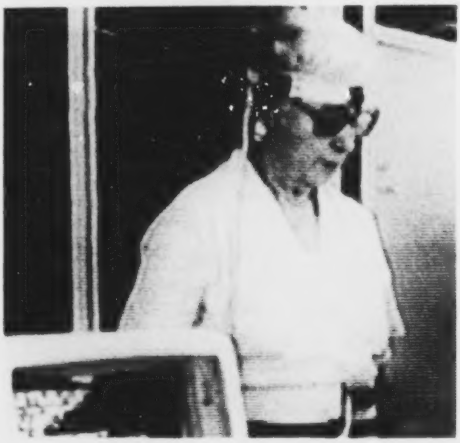


Fig. 1: B. TYPICAL SUBJECT - TANDEM WALKING (note eyes-down attitude)



In a typical laboratory test, subjects stand barefoot with feet apart and arms held at sides or on hips. 3-axis accelerometers are attached to the front and side of the forehead and waist using Velcro and elastic straps [Figure 1]. Sensor outputs are digitally recorded at 20 readings per second. To document displacement directly, reflective tape markers are attached to legs, trunk, arms and head; these are both conventionally videotaped and videophotographed at high contrast by a Motion Analysis system. Subjects then perform up to 20 tasks, including:

1. stand eyes open, then closed, for 15 sec
2. climb up 3 steps, turn, then down 3 steps
3. rise from and sit in chair at normal speed, then as fast as possible
4. tandem (toe-to-heel) walk 10 ft
5. walk over 2, 4 and 8 inch-high obstacles 3 ft apart

RESULTS

A total of 25 elderly (aged 64 to 85 years) and 5 young (24 to 29 years) female subjects were tested during the pilot phase. Mis-steps during toe-to-heel (tandem) walking were clearly identifiable, producing either vertical and anterior motion of the head apparently related to catching the toe on the floor, or lateral acceleration or sway [Figure 2]. During quiet eyes-open and eyes-closed standing, elderly subjects had lateral and pitch accelerations with more and higher peaks exceeding 0.01 G, increasing to about 0.05 G in the pitch axis with eyes closed.

We were also able to detect evidence of biomechanical sequelae of aging, such as greater transmission of heel strike shock to the head while climbing down stairs in elderly compared to young subjects [Figure 3]. The finding of amplification of acceleration peaks at the head in the elderly, instead of damping as in the young, is consistent with stiffening of shock-absorbing soft tissues such as intervertebral discs [5].

The time average of the antero-posterior (pitch) angle during rising from and sitting in a chair indicates a shift in orientation of the body relative to vertical or of the head relative to the body; a high standard deviation (SD) indicates unsteadiness in the pitch plane. During the act of sitting, young subjects' means varied randomly between trials, but elderly subjects' mean head-to-body angles were more often consistently positive or negative (tilting forward or backward) [Figure 4]. Standard deviation of elderly subjects was bimodal; eight were similar to young subjects while 5 ranged from 1.0 to 3.4 during rising. In the lateral plane during rising, SD of 15 elderly ranged from 0.1 to 0.8 radians, only six falling in the 0.1 to 0.2 range of the young [Figure 5].

The trunk angle relative to vertical during rising from a chair measured by accelerometers at the waist was consistently less that that derived from video image analysis of the line between hip and shoulder markers. The image analysis method could be overestimating the tilt angle since it cannot distinguish in-plane motion from rotation, while the accelerometers have a subject-specific shift due to body contour; this can probably be corrected by mounting one sensor in back instead of in front.

The stepping-over-blocks test is a new addition to the balance assessment protocol; it was performed by only three subject. One elderly subject was clearly similar to a young person in antero-posterior head-to-body angle (mean of -0.1 to +0.15, SD 0.8 to 1.2), while another had a mean angle of 0.24 to 0.42 radian and SD of 0.24 to 0.34 in 3 trials. This occurred in an individual with less confidence in her balance, who looked at her feet before stepping over each obstacle.

Fig. 2: TANDEM WALKING - ACCELERATION AT HEAD (X = pitch, Y = lateral axes); peaks circled

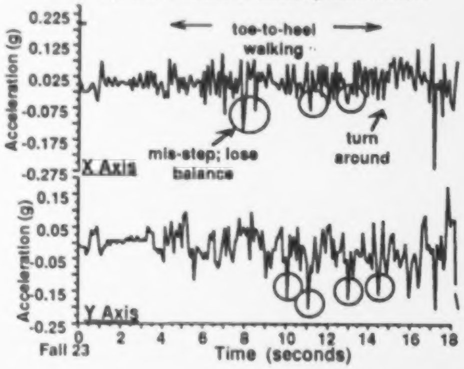


Fig. 3: WALKING DOWN 3 STEPS - RATIO OF HEAD TO WAIST ACCELERATION MAGNITUDE (3 runs, typical young & elderly subjects)

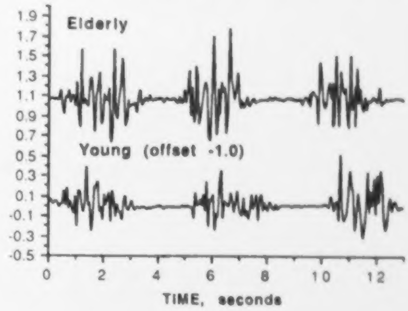
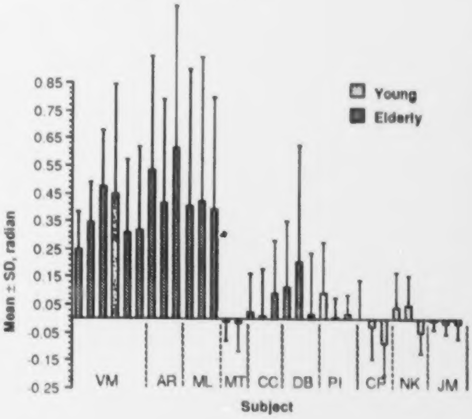


Fig. 4: SITTING IN CHAIR - PITCH ANGLE AT WAIST (2 to 6 runs per subject)



DISCUSSION

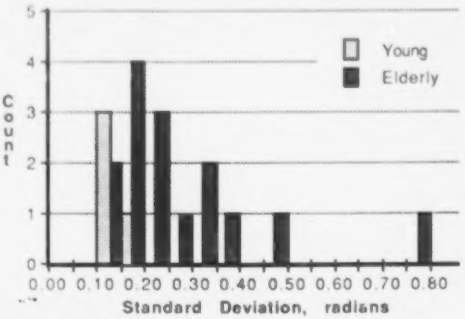
Piezoresistive silicon accelerometers are sensitive to constant accelerations as well as to transient changes in velocity. Thus, signals contain information on angle relative to gravitational acceleration, as well as motion-induced acceleration. If the signal is integrated without eliminating the gravitational component, velocities and displacements will be erroneous. By Einstein's equivalence principle, there is no theoretical basis for separating the gravitational and inertial components; one practical means is to begin integration when change in velocity is known to be zero and to recalculate and subtract the contribution of angle relative to vertical from the total acceleration at each time point. An alternative is to deal only with relative angles of adjacent body segments [6]. Piezoelectric sensors can detect only transients, and are insensitive to slow changes in velocity common in human motion; tests of these sensors have yielded poor correlation with total body motion [7].

An expanded three-year project has been approved for VA support beginning in October, 1990; it includes: (1) further development of hardware for measuring relative upper body accelerations, (2) refinement of present software for analyzing data to yield head and torso velocity vectors in real-time, (3) continued laboratory testing of well-defined motion sequences typical of activities of daily living, (4) continued comparison with simultaneous measurement of displacement by image analysis, to verify accuracy of results, (5) expansion of the subject population to include post-surgical patients, whose progress toward independent living is more rapid than that of the fall-prone elderly (in conjunction with a current study of Dr. Winograd's), (6) expansion to include institutionalized and community-living subjects, (7) integration of accelerometric analysis with other balance diagnosis techniques (one such, the "Equitest" will permit controlled induction of falls), and (8) exploration of reinforcement of fall-avoidance behavior modification using accelerometric feedback.

ACKNOWLEDGEMENTS

The assistance of Julia Martino, Nancy Kissinger and Antone Johnson is gratefully acknowledged. Supported by VA RR&D pilot grant E972-PA and Merit Review grant E601-RA to E. Sabelman, m/s 153, Palo Alto VA Hospital, 3801 Miranda Ave., Palo Alto, CA 94304

Fig. 5: **RISING FROM CHAIR - LATERAL ANGLE, VARIATION BETWEEN HEAD AND WAIST**



REFERENCES

1. Winter, D.A., Patla, A.E., Frank, J.S., Wait, S.E., "Biomechanical walking pattern changes in the fit and healthy elderly", *Physical Therapy*, **70:** 340-346, 1990.
2. Iqbal, K., Hemami, H., Simon, S., Pisciotta, J., "The dynamics and control of side to side sway in the frontal plane", *Proc RESNA 12th Ann Conf*, New Orleans, LA, June 25-30, 1989, paper 15.5, p. 127-128.
3. Pozzo, T., Berthoz, A., Lefort, L., "Head kinematics during various motor tasks in humans", *Progress in Brain Res*, **80:** 377-383, 1989.
4. Tinetti, M.E., Speechley, M., Ginter, S.F., "Risk factors for falls among elderly persons living in the community", *NE J Med*, **319:** 1701-6, 1988.
5. Light, L.H., McLellan, G.E., Klenerman, L., "Skeletal transients on heel strike in normal walking with different footwear," *J. Biomechanics*, **13:** 477-480, 1980.
6. Willemsen, A.Th.M., van Alste, J.A., Boom, H.B.K., "Real-time gait assessment utilizing a new way of accelerometry", *J Biomechanics*, **23:** 859-863, 1990.
7. Bálogun, J.A., Amusa, L.O., Onyewadume, I.U., "Factors affecting 'Caltrac' and 'Calcount' accelerometer output", *Phys Therap*, **68:** 1500-1504, 1988.

1.2

ASSISTIVE DEVICES AND THE ELDERLY: A SHOTGUN WEDDING?

M. Cherie Clark & Barbara R. Kline
Technology Center
Stein Gerontological Institute
Miami, Florida

ABSTRACT

The use of assistive devices to enhance independence for older persons has met with much resistance, particularly from potential older consumers themselves. While it is accepted by professionals that assistive products can and should be extended to older users, the way in which this could be easily accomplished is not clear. Results from a marketing survey conducted with persons interested in obtaining more information about assistive technology suggest that it is important to consider the needs of both potential older consumers and their caregivers in any marketing approach. Usefulness and quality of products appear to be the most important features of assistive devices according to the respondent sample. Both caregivers and potential older consumers expressed a need for more information concerning products and availability. Experience with health care service delivery to older persons suggests that the first line of information and referral may be physicians and pharmacists as these professionals are frequent and respected contacts of older persons who could benefit from the use of assistive technology.

BACKGROUND

A logical extension of the work in the use of assistive technology to enhance independence for persons with disabilities is to apply that knowledge and experience to assist older persons with daily tasks. As a group, the elderly represent the fastest growing segment of our population; by the year 2010, 1 out of every 3 persons will be over the age of 65. Furthermore, within this age segment, the fastest growing group is those over 85. What we know about this group is that they are all beginning to experience, to some degree or another, age related physical declines in ability. These declines greatly compromise their ability to remain independent in their own homes (1). Given the knowledge and experience from work in the disability field, we can speculate that assistive technology could have a significant impact on improving the functional ability of frail older persons. However, having older persons accept assistive devices has not been an easy task (2).

Serving the need of older persons with assistive technology is difficult given the evolution of many of these products. Most assistive products have traditionally been associated with medical or hospital environments and carry the stigma of "sick or frail". It is only recently that many assistive products have taken on a more "normalized" appearance. In most cases, however, these products are still displayed and obtained in medically oriented environments and are shunned by older persons who could benefit from their use. We have heard time and time again such remarks as, "I don't need that yet, and hopefully I won't ever get that sick." Too often older persons who know they could use a little help avoid all discussion of assistance since it forces them to deal with the fact that they are aging. From the gerontological literature, we know that most older persons imagine themselves as 10 to 15 years younger, not someone who is getting older and less able to complete daily tasks easily and safely. Products that remind them of frailty and illness are soundly rejected. As a result those attempting to prescribe and market assistive devices to older persons find themselves constantly in the position of trying to bring a reluctant groom to the altar with the shotgun of impending illness, disability or death, forcing acceptance of physical declines. We need to know more about this consumer group and develop products and distribution approaches that go beyond the obvious need and cater to more positive issues on order to have a chance at success.

OBJECTIVES

There are currently a large number of nice looking assistive devices on the market, along with many unattractive products. We have very little information about how appropriate many of these devices are for older users since most were not designed for this user group. There is a great need for eval-uation of current devices and development of new devices to serve this expanding group. More difficult issues currently lie in an age old problem, that of tech-nology transfer. We know from experience that the existence of the right devices and the right funding mechanisms is not enough to ensure that persons with needs will be served appropriately. While these issues are obviously important, Vanderheiden (3) and others point out that this is only a part of a whole service delivery model that is needed. For those of us working in technology and service delivery to older persons, we are struck with the fundamental knowledge gap that exists among service delivery professionals, older consumers, and device suppliers that if unchanged, will continue to impede the acquisition of technological assistance. We are in need of both good market research in this area and strong educational programs for professionals and consumers.

METHODS AND RESULTS

Knowing who are the target consumers and what is priority to these consumers is an important first step in good marketing plans (4). To this end, some initial information can be gleaned from a recent pilot marketing survey. After reading a syndicated article on low tech assistive devices for the elderly which appeared in local newspaper across the country, individuals contacted us requesting further information. Of the 400 surveys sent to the people who made these requests, 111 responded. In general, most respondents indicated that they had not known previous to the article that these products existed nor where they could be obtained. However, they all expressed a need for assistance with daily tasks due to arthritis, frailty, low vision, and many of the other age related physical changes. As such, these individuals represent an important potential consumer group.

Sixty five percent of the respondent group were relatives (most often children or grandchildren) inquiring about products for older relatives. Older consumers inquiring about products for themselves alone or for themselves and an other rela-tive made up 35%, of the sample. Additional data from this survey highlight the salient concerns of persons interested in assistive products. The most frequently mentioned were usefulness and quality of products. Many respondents reported that price of products is not as critical as usefulness and quality. Respondents expressed a need for more information on the range of products available for specific conditions and where these products could be obtained.

DISCUSSION

These data suggest several points for both marketing strategies and for service delivery. First, it is important to consider formal caregivers or relatives in any attempt to market assistive products to older persons. The data further suggest that it is important to develop products that are useful and of good quality. Respondents did not comment on appearance of products but it must be noted that pictures accompanying newspaper articles all highlighted up beat, modern, attractive, low tech assistive products. For many respondents, this was their first introduction to assistive devices and they reacted very positively to products displayed. Another important aspect of these data is the need for more information. Who should provide this information? Distributors of products often feel that they should play an important part here. The need for profes-sional evaluation, training, modification, and monitoring of many devices would suggest that Occupational Therapists and Rehabilitation Engineers may be the best information sources. In fact, the trend in service provision now is the multidisciplinary team, each providing appropriate input and guidance. However, it is important that members of this team be trained in gerontological and assistive device issues to better serve older persons.(5)

How does a potential consumer or caregiver find out about these teams and how accessible are they? We are more and more convinced that physicians and local pharmacists are critical partners in the service team. We know that older persons see physicians on some regular basis and trust their advice. We also know that the local pharmacist has considerable influence in the lives of the elderly. The physician and pharmacist are likely to be the most frequent and possibly only contact older persons have with medical professionals. As such, their roles as a potential source of referral to the delivery team should not be underestimated; they can only help to ensure a more positive marriage of assisstive devices and the elderly to enhance independence.

REFERENCES

1. National Center for Health Statistics (1987b). R.J. Havlik, B.M. Liu, M.G. Kovar, et al.: Health statistics for older persons, U.S., 1986. Advance Data from Vital and Health Statistics. Series, 3, No. 25. DHHS Pub. No. (PHS) 87-1409. Public Health Service. Hyattsville, MD, June, 1987.
2. La Buda, D. (Fall, 1986). Bringing gerontologists and technologists together, What's the problem? Generations, 11, 8-10.
3. Vanderheiden, G. Service delivery mechanisms in rehabilitation technology. The American Journal of Occupational Therapy, 41(11), 703-710.
4. Evashwick, C. (Summer, 1984). Marketing services for seniors. Health Marketing Quarterly, 1(4), 19-32.
5. Somerville, N., Wilson, D., Shanfield, K., & Mack, W. (1990). A survey of assistive technology training needs of occupational therapists. Assistive Technology, 2(2), 41-49.

M. Cherie Clark
Technology Center
Stein Gerontological Institute
5200 N.E. 2nd Ave.
Miami, FL 33137

WALKER PERFORMANCE EVALUATION BY A PANEL OF OLDER WALKER USERS

John T. Ward, Margaret A. Wylde, and Elaine R. Cremaldi
Institute for Technology Development
Oxford, MS 38655

ABSTRACT

This report summarizes the results of a consumer evaluation study undertaken to observe the performance of older, experienced walker users when using four styles of walkers. The primary objective was to explore the user-product interaction as each subject used and evaluated each walker on two flat surfaces and a ramp. The results were compared among the individual walkers and across the groups of walkers. All testers achieved their best performances with four-wheeled walkers but some testers preferred the security, and slower pace, of non-wheeled walkers.

BACKGROUND

This study was begun because older users do not seem to be making full use of available walker styles. Health conditions that affect mobility increase with older adults and older adults use more mobility devices than do younger adults. Although walker equipment is available in varied configurations and accessories, doctors and therapists are prescribing the rigid, non-wheeled walker for the over 65 year-old user. People are either unaware of the availability of consumer choice in walker style or they perceive that wheeled walkers are "too much" for the older user.

History of walker design

The walking frame, introduced about two hundred years ago, was created solely for rehabilitation purposes. The design of the standard, rigid, non-wheeled frame (pickup and put) was conceived as portable parallel bars enabling the patient to take gait training out of the therapy room and into the hospital corridors (Cress, 1982).

Many people use a walker for an extended time. Walkers are frequently prescribed for residents at convalescent or retirement facilities to help ambulation, and to enable them to gain confidence and walk unaided without risk of falling. Even if the prescription for the walker specifies temporary use, users tend to perceive the walker as a permanent aid to ambulation. Black (1980) reported 43.1 percent had used a walker for one to four years, while 26.1 percent had used a walker for five years or more.

Walker users

Numbers of users. The U.S. Dept. of Health and Human Services estimates, the total number of walker users in the United States in 1977 was 689,000, or approximately 3.2 people per 1000 of the noninstitutionalized population. This figure had risen from 2.0 walker users per 1000 in 1969. In 1969 there were 17.6 walker users per 1000 persons 65 years and over; in 1977 this number increased to 24.7. In the population 75 years and over, there were 34.5 walkers users per 1000 persons in 1969 and 47.6 in 1977 (Black, 1980).

RESEARCH QUESTIONS

The purposes of this study were to:

1. Evaluate a representative sample of walkers using a panel of older walker users.
2. Collect information about walker use from groups of older walker users.
3. Evaluate the impact of walker features on the usability by the intended users.

METHODOLOGY

The project comprised two parts: focus group research and laboratory evaluation of walker use.

Focus groups

Three focus groups were conducted. Two groups met in Oxford, MS among participants of the laboratory study after the usage trials. The members of the group in Memphis, TN were walker users, some of whom had participated in another research project.

Usage trials

The purpose of the usage trials was to assess the abilities of the 55 year old and older user to use various walker styles. The specific objectives of the study were to:

1. Identify the benefits and limitations of walker features.

2. Compare the differences in user performance with walkers with no wheels, two wheels, and four wheels.

Walker equipment

Before beginning the study, a meeting was held in Milwaukee, Wisconsin, with representatives from ten walker manufacturers and distributors from the United States and Canada. The meeting was held to explain the purpose of the study, solicit participation, and gain suggestions and insight into the conduct of the study.

The walker manufacturers invited to participate were all those producing walkers as identified through searches of the 1989 Medical Devices Register and The Thomas Register. Twenty manufacturers participated in the study.

Each manufacturer was asked to submit walkers under four categories:

Group 1. Rigid Walkers that are the standard product prescribed for Medicare recipients. They were not to have wheels.

Group 2. Folding Walkers without wheels.

Group 3. Two-Wheeled Walkers.

Group 4. Four-Wheeled Walkers including both traditional and the newer styles of wheeled walkers.

Subjects

The criteria for participants in the laboratory evaluation were: (1) 55 years of age or older, (2) current use of a walker or usage during the previous year, (3) ability to come to the test site, and (4) ability to participate in the evaluation tasks. Transportation was provided if needed.

Procedures

The walker height was set by aligning the top or grips with the top of the subject's thigh. At this height, the subject's shoulders were to be level and elbows flexed comfortably at 20-30 degrees (angle measured from the vertical to the lower arm).

Measures of time and number of steps required to traverse were recorded for two flat surfaces 25 feet in length and on a 20 foot incline with a grade of one inch rise for every 12 inches in length. The flat surfaces were (1) a hard, painted wood track and (2) a carpeted track with one-half inch pile inclusive of backing. Subjects walked the length of the marked track, turned and walked back. The testers were asked to walk quickly without racing or endangering themselves. Crossing a busy intersection with the light was the reference for walking speed.

RESULTS

Subjects

Eighteen subjects ranging in age from 51 to 86 years, with an average age of 72.9 years participated. Eighty-four percent were women, 42 percent were Caucasian, and 58 percent African American. The subjects reported several conditions that caused their physical limitations including broken bones, weakness, balance problems, paralysis, amputation, hip surgery, and arthritis. The greatest number of the subjects (31.6 percent) had used a walker because of a fracture, including a broken hip. Falls or accidents (38.8 percent) and arthritis (26.3 percent) were the two major precipitating factors.

Analysis

The two performance measures, time and number of steps to walk a set distance, were highly correlated ($r = 0.97$). Average walking speed was 1.4 feet per second at a rate of 1.5 steps per second. The slowest pace was set with the rigid walkers with a time of 0.75 feet per second at a rate of 1.2 steps per second. The fastest rate was produced by the four-wheeled walkers which travelled at a speed of 1.7 steps per second.

A two way analysis of variance (ANOVA) was conducted on individual walkers and walkers categorized by group for each of the two performance measures. All four ANOVA tests showed the differences between walkers and groups of walkers to be highly significant ($p < 0.0001$) and the differences between performances on different surfaces to be insignificant ($p > 0.10$).

Student-Newman-Keuls post hoc procedures were used to group the groups and individual performance ratings. The four-wheeled walkers as a group were found to produce faster walking speeds and longer step distances than were any of the other three groups. The two-wheeled walkers were slower than the four-wheeled walkers but faster than the non-wheeled walkers at an alpha level of 0.05. Both wheeled walker groups were significantly faster than the non-wheeled groups. The two non-wheeled groups were not found to differ from one another significantly at an alpha level of 0.05.

Only one four-wheeled walker and four two-wheeled walkers fell in the group of twenty walkers with below average performance scores. In the group of twenty walkers with above average performances there were only one rigid walker and three folding walkers. Sixteen of the top twenty performances came from wheeled walkers. Fifteen of the twenty worst performances came from non-wheeled walkers.

DISCUSSION

When subject walking times are summed by groups across surfaces every subject walked faster with the wheeled walkers than with the non-wheeled walkers. However, not all subjects preferred the wheeled walkers. In focus group discussions the frailest subjects expressed strong dislike for the walkers with wheels. Their stated objection was that even though they could travel faster with the wheeled walkers they felt less secure. One subject expressed her feelings by saying, "The wheeled walkers act like they have a mind of their own."

Subjects who expressed a strong desire to maintain their life style in spite of the effects of aging and disability preferred the faster speed and more natural walking pattern that they experienced with wheeled walkers. Less stable subjects who wanted a walker for security and to prevent falls preferred the non-wheeled walkers. All subjects exhibited a faster pace and more natural leg motion with the four-wheeled walkers.

ACKNOWLEDGMENT

Funding for this research was provided by the American Association for Retired Persons, Washington, D.C.

REFERENCES

Black, E.R. 1980. Use of special aids, United States-1977. (DHHS Pub. No. (PHS 81-1563). National Health Survey, no. 135, National Center for Health Statistics. Hyattsville, MD: Public Health Service.

Cress, R.H. 1982. Ambulation aids for the elderly. Medical Instrumentation, 16(3):169-170.

2.1

MOBILE ROBOTIC PLATFORM CAPABLE OF FOLLOWING A HUMAN COMPANION

Lincoln A. Jaros, Ulrich Raschke, Simon P. Levine, Johann Borenstein
Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation
Mobile Robot Laboratory, Department of Mechanical Engineering
University of Michigan

ABSTRACT

A pilot research study is underway which will develop and demonstrate several capabilities necessary to build a mobile robotic platform (mobile robot) which can detect and follow a human companion as the companion moves about in a real world setting. Such a robot must be able to measure the direction and approximate distance to its intended companion. It must then combine this and other environmental data to execute *following* movements. This paper outlines the sensor systems and computational strategies currently being employed in this research.

BACKGROUND

A variety of rehabilitation applications for a mobile robotic base have been proposed. These include performing delivery and retrieval activities, moving assistive equipment such as robotic arms and environmental control systems from room to room, and acting as an activity guidance system or navigator for a patient with cognitive impairments. Each of these tasks makes similar demands of the robot. For each, the robot must be able to move about in the environment without running into people or objects. It needs to perform this *obstacle avoidance* in real time without significant slowing. • The robot must always know its current location in the global map of the environment (*absolute position*), and based on this location, be able to calculate the path it must trace to reach any other given location or room (*global path planning*). Progress towards these two goals has been reported elsewhere(1,2).

Another important requirement is that the robot be able to keep track of and follow a human companion. This frees the companion from providing continuous directions when the robot is to follow. Another valuable outgrowth of *companion-following* is the ability to lead a companion who is unsure alone, due either to the complexity of the environment or to some level of cognitive impairment.

STATEMENT OF THE PROBLEM

Companion-following has two aspects. The first is *companion-tracking*. The robot must be able to detect the location of its intended companion at all times. The second aspect of *companion-following* is locomotion. The robot must use the sensory information about companion activity to stay close. In a real environment these *following* movements must incorporate information about detected obstacles, as well as data about the companion. The strategy involved in achieving safe locomotion through obstacle detection and autonomous navigation is discussed in other published reports from this study(1,2,4).

The key to successful *companion-following* is adequate information about the companion's behavior. In particular, the robot must be able to detect the direction to and the approximate distance from the companion. Direction information tells the robot how to approach the companion. Distance data indicates when the robot is close enough to stop its approach.

Ideally, position measurement of the companion should occur several times each second. A high sampling rate provides two advantages. By sampling frequently and averaging readings, the robot can tolerate less accuracy in individual sensor readings. Lowering the required accuracy lowers the price and complexity of sensor systems.

The other advantage of high sampling rate concerns the *obstructed view* problem. In an environment empty of everything except the companion and the robot, the *tracking-following* exercise consists solely of moving toward the companion whenever the companion moves away (i.e., distance to companion increases). The real world introduces many obstacles such as walls and people. Virtually all detection systems depend on a *line-of-sight* connection between robot and companion. For example, the infra-red (IR) detection system used in this project will fail if an object is placed between the IR light source and the IR detector. In practice, the *line-of-sight* connection between robot and companion is constantly being interrupted when someone walks between the two or when the companion moves behind any object.

When the robot loses contact, it must rely on information it already has to plan a strategy which will result in reestablishing *line-of-sight* contact. Here a rapid data sampling rate is invaluable. By comparing successive readings recorded just before loss of contact, the robot can estimate course and speed of the companion. Based on this estimate and the robot's acquired knowledge of obstacles in the environment, it can decide how best to find the companion.

The sensor equipment is part of the solution to *companion-tracking*. The other part is behavioral strategies built in to the control software of the robot. The two chief tracking problems this software must face are mentioned above. The first is moving the robot to follow the companion in an unobstructed environment. More difficult is dealing with the obstructed view problem caused by static and dynamic obstacles.

APPROACH

The platform used in this research is a commercially available robot manufactured by Denning Mobile Robotics[a] for security applications. The Denning DRV-1W is a three-wheeled robot designed so that all wheels are driven and all wheels steer together. It combines the following subsystems (see Figure 1):

Onboard *Master Control* Computer This is an IBM-compatible 80386-based computer. It is responsible for all sensory integration, *obstacle avoidance*, *companion-tracking* and control decisions.

Ultrasonic Ranging Ring The robot is surrounded by a ring of 24 Polaroid ultrasonic transducers mounted radially at 15° intervals. Each sensor can be fired individually, and provides information about the distance to the nearest obstacle in the direction the sensor is facing.

Infra-Red Beacon Detector[a] An infra-red (IR) sensitive camera is mounted in such a way that it may be rotated freely through 360°. The system detects specially designed IR beacons in the environment around the robot and provides accurate direction information to these beacons.

The beacon used is a simple, battery-powered circuit driving an IR light emitting diode (LED). Sixty times each second this LED flashes a serial seven-bit digital code. Each beacon can be set to a unique code, allowing the robot to distinguish between several beacons. For the tracking task, a beacon circuit will be mounted on a belt to be worn by the companion. By spacing 3 or 4 LEDs around the belt, the robot's camera will be able to see the belt regardless of the companion's orientation.

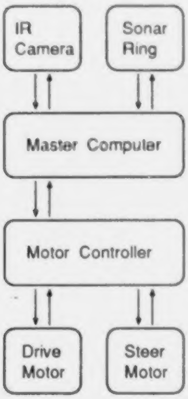


Figure 1. Block Diagram of Mobile Platform

The IR system provides the robot with information about the direction to the companion. From this direction, the robot can determine which of its sonar sensors is pointing at the companion. The distance to the companion can then be determined from the real-time obstacle map constantly being updated by the sonar software. Using distance and direction, the robot will continuously update its estimate of the location of the companion, and move to stay near. The goal is to have the robot remain within a range of 0.5 to 2.0 meters, even with other people and obstacles crossing between the robot and companion.

The control algorithms for *companion-following* have two objectives. The first is to execute basic movement commands. When the companion moves away, the distance between companion and robot will increase. The robot must respond with motion commands to follow. The speed that the robot moves is a function of several factors, including the current distance from the robot and the speed and direction of the companion.

The second objective is to handle the *obstructed view* problem introduced earlier. When the robot looses sight of the companion it must decide how to proceed. The initial approach is to have the robot follow a set of rules to attempt to reestablish contact:

1) Store the current robot location, the companion's last estimated location, course and speed as well as the current local obstacle map. The estimate of companion course and speed comes from comparing successive recent location estimates. The local obstacle map is a product of existing obstacle avoidance software. It is a continuously updated picture of obstacles around the robot.

2) If the companion was stopped or almost stopped before loss of contact, pause for several seconds. This will prevent unnecessary or jerky motion in response to momentary interruptions, as when a second person walks in front of the standing companion.

3) If the companion was moving, or after the pause time has expired, move the robot from its current location to the last estimated location of the companion. The speed of the robot before loss of contact determines the speed of this move. If the robot was actively *following*, it will continue at speed. If it was stopped, it will approach slowly.

4) While approaching the last estimated location, scan for the IR beacon in the general direction (±45°) of the companion.

5) Having arrived at the estimated location, scan for the beacon through 360°.

6) Stop active scanning, but wait for movement detected by local map comparison. This is an experimental idea aimed at detecting possible locations of the companion. When contact is lost,

the robot records the local obstacle map. By comparing this original map with the current map it should be possible to identify new centers of motion and activity around the robot. The robot can then go to step 3 above and approach the area of movement.

IMPLICATIONS

The current approach imposes several conditions. The companion must wear some article to hold the IR beacon. This is not expected to present a problem, since this circuit is only slightly larger than that contained in other, commercial LED jewelry and novelty clothing items.

A more important shortcoming of the current configuration is the mounting of the IR camera. At present this detector is attached so that it turns in unison with the robot's wheels. In order to turn the detector, it is necessary to turn the robot. The detector has a view angle of 20° so that most of the time this is not a problem. However, when the robot loses sight of the companion and must search a wider field of view it is almost essential to stop the robot before performing the scan. In the future, it will be desirable to mount the IR equipment so that it can be rotated separately from the wheels. Without this addition, following is more difficult, while leading a companion is not practical.

The methods used for *companion-following* were partly dictated by the equipment already available on the robot. Background research failed to identify other techniques which had a clear advantage over the sonar-IR combination chosen. Most other promising technologies currently suffer from unacceptable cost or excessive requirement of development time.

DISCUSSION

Previous research and testing in the laboratory has demonstrated the efficacy of the hardware used in this project. The IR system has been used successfully to allow the robot to compute its absolute location and orientation. Three beacons are mounted at known locations on the room walls, permitting the robot to find its position by triangulation. Under best conditions the distance between robot and beacon can be as much as 14 meters, well beyond the 5 meter range maximum projected for *companion-tracking*. The sonar equipment and navigation software has displayed similar proficiency in the laboratory. Rapid sampling and innovative data reduction can produce accurate obstacle maps, even though individual sonar readings are somewhat unreliable.

Future research will show whether the combination of these two systems will enable practical *companion-following*. An important component of this research is testing of the final configuration. This testing will occur in several stages. Initially, the robot will perform only in a carefully controlled laboratory setting. Subsequent trials will introduce more complex situations, including moving obstacles (persons and carts) and environment barriers (doorways and halls). The final test for a successful design will be to face these situations in a real world environment.

ACKNOWLEDGEMENTS

This work is funded under a pilot grant (Number B991-PA) from the Department of Veteran Affairs Rehabilitation Research and Development Service.

REFERENCES

1. J Borenstein, SP Levine, Y Koren: "Ultrasonic Sensor System for Mobile Robot Obstacle Avoidance and Navigation". Proc. of 1990 International Conference on Rehabilitation Robotics. pp. 121-131, 1990.

2. Y Zhao, SL BeMent, J Borenstein: "Dynamic Path Planning for Mobile Robot Real-Time Navigation". Proc. of the 12th IASTED International Symposium on Robotics and Manufacturing, 1989.

3. SP Levine, J Borenstein, U Raschke, TE Pilutti, Y Koren, SL BeMent, N Kirsch: "Mobile Robot System For Rehabilitation Applications". Proc. of the Twelfth Annual RESNA Conference, pp. 185-186, 1989.

4. L Jaros, SP Levine, J Borenstein, T Pilutti, U Raschke: "Fail-Safe Features of a Mobile Robotic Platform". Proc. of the Thirteenth Annual RESNA Conference, pp. 291-292, 1990.

MANUFACTURERS

a. Denning Mobile Robotics, 21 Concord Street,
Wilmington, MA 01887, USA

ADDRESS

Lincoln Jaros
Rehabilitation Engineering Program
1C335 University of Michigan Hospital
Ann Arbor, Michigan 48109-0032, USA

2.2

INTERACTIVE ROBOTICS : APPLICATIONS IN MANUFACTURING INDUSTRY

R.G. Gosine, R.D. Jackson
University of Cambridge
Cambridge, England

D. Scott
The Papworth Group
Papworth Everard, England

T. Jones
Oxford Intelligent Machines
Oxford, England

Introduction

Rehabilitation robotics research, which is concerned with the provision of assistance to people with motor disabilities, has concentrated on three primary application areas - daily living activities, educational activities, and vocational activities. The success of such research projects has been mixed and has been influenced by many factors. In the vocational applications, the success has largely been restricted to projects involving highly motivated individuals who have acquired a physical disability after becoming skilled at a particular job. This has been true of the successful application of interactive robotics in Seattle[1] and Palo Alto[2] in the USA, and Malmo[3] in Sweden where robotic devices have been used as support in computer-oriented vocational activities. The application of simple robot systems has made it possible for a small number of people to return to their original place of employment. Associated with each of these successful applications has been the desire of the employer and co-workers to assist a colleague who had become disabled to the point of being incapable of vocational activity without assistance. This motivation to employ and assist a highly skilled colleague in need is exceptional and cannot be taken for granted by the many physically disabled people who are unable to take advantage of employment opportunities.

The research described in this paper attempts to look beyond the exceptional cases and identify generic activities within manufacturing industry where human decision-making ability is required and the person may be trained on-the-job. Many people with severe physical disability from birth have a restricted primary education and little secondary education. It is unlikely, therefore, that there will be widespread prospects for jobs such as computer programming which requires an advanced secondary education. In this sense, the approach is closer to that taken at the Cerebral Palsy Research Foundation[4] in Kansas and the IRV[5] in Holland where robots have been used to enable physically disabled people to participate in light manufacturing activities.

Role for Automation

Automation is commonly considered for application in manufacturing industry as a means of increasing productivity on repetitive assembly tasks. Attempts to automate production processes fully have been hindered by the relatively slow development of suitable technology, the rapid development of the technology incorporated into the product, and the reluctance of industry to invest in technology which is expensive in comparison with human labour. It is known that automation is successful for high volume, rigidly structured tasks that require little decision-making. For tasks that require human decision-making, however, full automation is impossible.

Consider the technology associated with the production of electronic circuit boards. While there are advances in production processes, there are even more rapid advances in the technology associated with the products. Although it may be possible to develop and apply an automatic visual inspection system which can detect flaws associated with conventional pcb fabrication methods, this would amount to solving yesterday's problems with today's technology. In view of this, it is likely that for the foreseeable future there will remain a need for human sensing facilities and the ability to adapt to different inspection tasks.

It is in manufacturing scenarios which rely on human decision-making that people with impaired motor function may use appropriate handling devices to carry out the limited manual tasks within a more complex activity. Demographic changes are resulting in an ageing population, a shrinking labour force, and as a result, a need for industry to consider a wider source of labour.

Research Summary

The current project represents a collaboration between researchers with an interest in rehabilitation engineering, researchers with an interest in production processes, vocational placement officers with a particular interest in the assessment and placement of people with physical disabilities, and industries involved in manufacturing. The research is currently focusing on two aspects of the general problem. From an engineering perspective, an survey of industry is being carried out to identify interested manufacturing industries, the employment needs of the industries, and jobs within the industries which require a high level of human decision-making and limited manual dexterity. In parallel with this survey, current employment assessment procedures are being considered with a view to developing worksamples and assessment procedures to evaluate the performance of a human using an interactive robot to carry out selected manufacturing activities.

Exploration of Production Processes

As of December 1990, a series of thirteen industrial visits have been carried out in a search for practical applications of interactive robotics in mainstream production industry. These visits were based on promising responses to a mailshot and follow-up telephone appeal to 250 manufacturing industries in the Cambridgeshire area. The initial contact with the industries described the interactive robotics project and requested the help of industry in identifying practical applications. The encouraging level of interest from industry may be attributed to both altruistic and economic considerations. The latter consideration is particularly encouraging since it indicates the growing need for certain industries to consider unconventional sources of labour.

Prospective applications have been identified primarily in the quality control aspect of the production where some simple material handling is involved. The activities fall into one of the following categories: electronics production/inspection, inspection of machined parts, bench-top chemistry activities, specialised quality control, and general materials handling. Examples of promising activities include the visual inspection of electronic circuit boards, the visual inspection of the surface of machined parts, the visual inspection of seed samples and plant clippings, and the subjective evaluation of the base chemicals used in fragrance production. The prospective applications are currently being assessed to determine methods of introducing interactive robotics into the production process and to determine the implications of such an approach to the manufacturing process.

Assessment

In parallel with the consideration of the issues related to manufacturing engineering, consideration is also being give to the assessment of an interactive robot system[6] as a vocational assistant. In order to carry out this assessment, a worksample is under development which allows productivity to be measured. The task will be representative of the activities which have been identified as possible candidates for the interactive robot approach, while the selection of candidates will be based on standard cognitive and physical assessments such as visual acuity tests, cognitive reasoning tests, and range of motion tests.

It is proposed that a person who, having been identified as a prospective candidate for the interactive robot approach, performs badly at the assessment activity may do so for two reasons. First, the person may not be motivated to carry out the particular job function. Second, the human-robot interface may not be appropriate for the person and may be confusing or difficult to access. The former result indicates a mismatch between the job and the person while the latter requires modification to the system. Both of these results, in addition to feedback from the people who achieve good performance at the activity, will provide valuable insight for subsequent system development and potential application areas.

In view of this, the assessment activity will have a two-fold purpose. In the short-term, information will be gathered to provide a comparison of assisted and unassisted performance at simple quality control activities. The average productivity rate for representative operations could be determined from a broad spectrum of able-bodied workers in the industries. Similarly, the average rate for a worker with impaired hand/arm function who is currently employed in an industry would be determined. Finally, the production rate for a disabled person in combination with a robot would be determined and compared against the production rates for the groups of currently employed workers.

It is quite likely that a complex manipulation component of an activity which can be completed by a simple robot will be completed faster and more accurately by an able-bodied person. It is important, therefore, that manipulation not dominate the practical application or the assessment activity.

Parity between a disabled worker/robot and an able-bodied worker is unlikely although it is possible that a range of activities exists which fall within an acceptable productivity level. The range of tasks will depend on whether the comparison is with the able-bodied workers or those with some manipulation impairment. The aim of the project should be to enable a person to reach a relatively high-level of productivity as compared with able-bodied workers. An acceptable level within a sheltered workshop setting may be lower although it must compare favourably with the baseline for current employment within such a workshop.

Acknowledgements

The authors would like to thank the ACME Directorate of the Science and Engineering Research Council for supporting this research. Also, the valuable contributions of Mr John Gibson, of the Papworth Group, and Mr John Gatiss, of the Cambridge University Engineering Department, are appreciated.

References

(1) Fu, C. (1986). An independent vocational workstation for a quadriplegic. *Proceedings of the 9th Annual Conference on Rehabilitation Technology*, Minneapolis, U.S.A., 182-184.

(2) Hammel, J., Hall, K., Lees, D., Leifer, L.J., Van der Loos, M., Perkash, I., Crigler, R. (1989). Clinical evaluation of a desktop robotic assistant. *Journal of Rehabilitation Research and Development*, **26**, **3**, 1-16.

(3) Levin, S.O. (1990). Personal Correspondence. AMU HADAR, Malmo, Sweden.

(4) Anderson, L.L. (1986). Small robot arm in the workplace to aid in the employment of severely physically disabled persons. *Proceedings of the 9th. Annual Conference on Rehabilitation Technology*, Minneapolis, U.S.A., 244-246.

(5) Soede, M., Foulds, R.A., Martens, P., Thierry, P.J. (1987). Workplaces for the handicapped in flexible production automation with robots. *Proceedings of the 10th Annual Conference on Rehabilitation Technology*, San Jose, U.S.A., 805-807.

(6) Gosine, R.G, Harwin, W.S., Jackson, R.D. (1990). Vocational assessment and placement: an application for an interactive robot workstation. *Proceedings of the 13th Annual Conference on Rehabilitation Technology*, Washington, U.S.A., 293-294.

Contact Address

R.D. Jackson
Cambridge University Engineering Department
Trumpington St, Cambridge
CB2 1PZ, England
Fax: 44-223-332662

2.3

Factors in the Prescription and Cost-Effectiveness of Robot Systems for High-level Quadriplegics

J. Hammel, MA, OTR & H.F.M Van der Loos, EDME
Rehabilitation R&D Center and Spinal Cord Injury Center
Palo Alto Veteran Affairs Medical Center
Palo Alto, CA USA

Abstract

In order to ensure the successful implementation and acceptance of robotics technology for severely disabled employees in the vocational setting, protocols must be setup to analyze disabled user needs, the technology transfer process, reimbursement and cost-benefit issues. To illustrate this critical process, the methods for the design, development and evaluation of the Desktop Vocational Assistant Robot are described.

Background

The design of the Desktop Vocational Assistant robot (DeVAR) was prompted by the goal to increase the independence of high-level quadriplegics in the workplace (see Figure 1). Beyond the technical challenge of designing an effective and robust robot system to replace attendant care, the research team needed to address technology transfer, cost-benefit, user assessment, and reimbursement issues.

A user and task assessment protocol is now in place to assure an effective incorporation of the robotics technology in a disabled person's existing work setting. In addition, overtures to insurance companies and third-party reimbursement agencies have made us aware of the crucial issues involved in the prescription of this type of device.

The installation of DeVAR at Pacific Gas & Electric (PG&E) Company in the office of a high-level quadriplegic programmer, and the continuous use of the system over an 18 month period, have allowed us to explore the problems and factors involved in a scenario typical of future realistic cases.

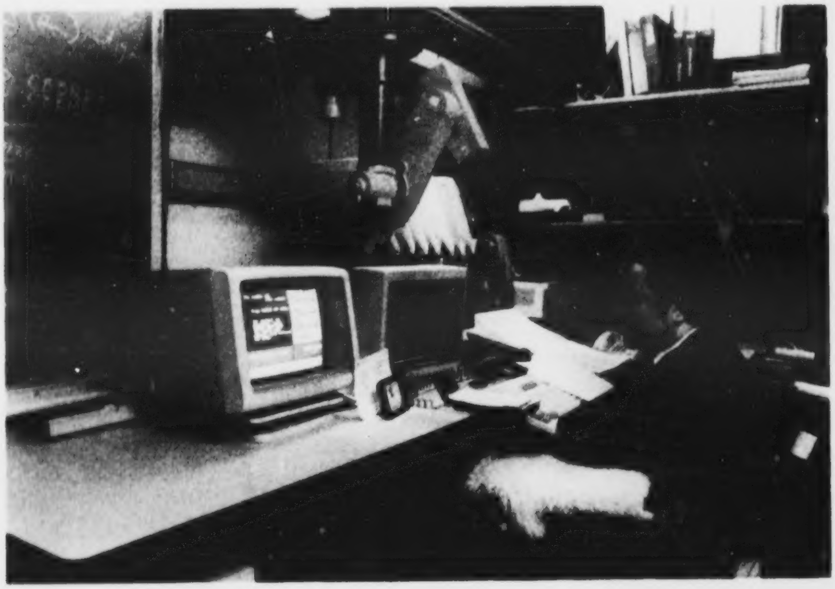


Figure 1: Quadriplegic employee uses DeVAR to perform daily living and vocational tasks in the office setting.

Research Question

Based on feedback from reimbursement specialists, and based on the cost and nature of the technology in question, our hypothesis is that a robot system will be an effective alternative to human attendant care in the workplace when it can reliably replace the attendant for a minimum of one 4-hour contiguous timespan.

In order to replace the attendant, the robot must be capable of performing all required tasks, including daily living and vocational tasks, reliably, safely, and in a timely manner. The disabled employee must be able to independently control the robot system. Voice control was chosen as the primary control method for the DeVAR system. A backup control method must also be provided for occasions when voice recognition becomes temporarily unreliable (high ambient noise,etc.). The DeVAR system provides a backup mouthstick to the user for sending commands via the keyboard as well as a separate serial port link to, for example, the employee's application computer.

Multiple safety features are essential if the employee is left unattended for a long period of time. On the DeVAR system, the user is able to stop the system via three modes: saying the command "STOP", making a loud noise, and pushing the emergency stop switch mounted near the user's face. Spasms can occur frequently among individuals with high-level spinal cord injuries and can range in severity, sometimes causing the individual to lose his/her positioning in the wheelchair. To safely accommodate for these spasms when the individual is left unattended, an emergency call system independent of the robot or phone operation must be provided. All of these criteria must be met before third-party reimbursers will consider the robot as a viable alternative to the attendant.

Methods

Based on the activity analysis of the typical day in the life of PG&E's quadriplegic employee (RY), DeVAR was designed and programmed to perform both daily living (fetch a drink, dispense medications and throat lozenges, serve lunch, scratch face) and vocational tasks (manage papers, operate the phone, fetch printouts, fetch mouthstick). This task repertoire was implemented before the system was placed in the worksite to minimize employee disturbance and initial system malfunctions. Several tasks were identified only after the system was installed as the user realized the robot's capabilities. DeVAR was installed in RY's office in July, 1989. Following an initial adjustment period, the robotic system has been used on a daily basis for the past 18 months, requiring maintenance engineer work approximately once a month. Automatic computerized history list capabilities were implemented to allow the research team to analyze the robot performance throughout each day and track any problems with the system.

A two-part (B-A), single-subject study was done to compare the performance of the robot versus the attendant in performing manipulation tasks. In the first part, RY was asked to use the robot for all manipulation tasks, limiting the use of the attendant to set-up tasks, tasks outside the office, and emergency assistance for a period of six 10-hour days. In the second part, RY used the attendant only for four 10-hour days. Two observers recorded all activities. Evaluations were compared with computerized history lists and extended play videos of the attendant.

Results

Results of the study supported the hypothesis, demonstrating that the attendant could be replaced for two 5-hour shifts, given access to emergency assistance if needed. It was determined that all tasks the robot was incapable of performing, such as complex paper sorting and mail retrieval, could be delegated to set-up times, thus limiting the role of the attendant to setup in the morning, lunch hour, and evening. In doing this, the attendant could then be available to perform a low-level job for the company and remain available to a number of disabled employees on an emergency basis, thus benefitting both the company and employee.

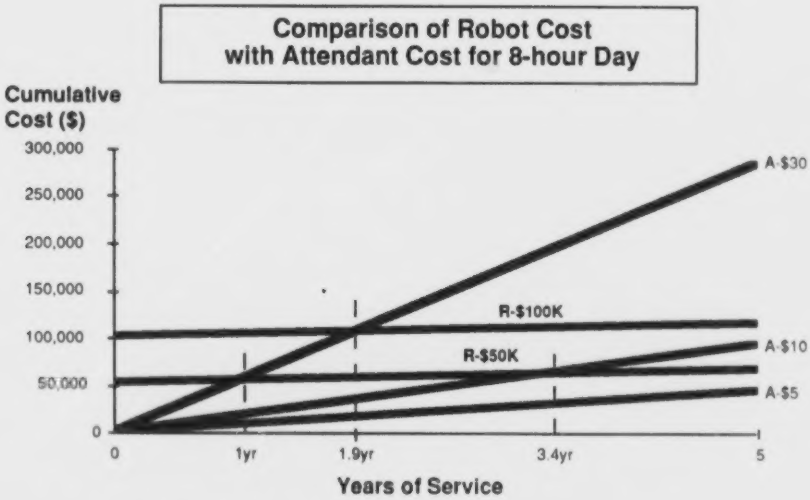
Results also indicated that DeVAR could offer a cost-effective alternative to attendant care (see Figure 2) (Van der Loos, 1990). Insurance companies typically pay for attendant care on a 4-hour shift basis at $30 per hour. Taking into account the initial cost of the robot system ($100,000) plus annual maintenance costs, the initial investment of DeVAR could be recouped in 2 years given the replacement of the attendant for two 4-hour shifts. A non-trained attendant, such as RY's, costs between $5 and $10 per hour. In RY's case, he could recoup his attendant costs entirely in 5 years.

This demonstration of the economic feasibility of DeVAR versus an attendant has led to a cooperative R&D Agreement between the Department of Veterans Affairs and a local startup company to commercialize the DeVAR system and transfer the technology to the disabled and corporate community.

Discussion

Since robotic technology involves a large initial investment, several suggested alternative scenarios for reducing this cost and increasing the overall benefit should be explored in order to provide incentives for the adoption of this technology in the workplace. Robots which have been taken out of factory settings can be refurbished and purchased at substantial discounts for use in DeVAR workstations. Additionally, one robot workstation could be shared by two disabled employees working separate shifts or redesigned to accommodate two desks during the same shift.

With the recent passage of the Americans with Disabilities Act (ADA), incentives also exist for government assistance in the reason-able accommodation of a disabled employee. Since ADA prohibits the discrimination of any qualified job applicant based on the person's disability, it is expected that technology such as DeVAR, which can offer cost-effective independence to the disabled employee, will become more commonplace in the future.



Attendant costs: $5, $10, $30/hour.
Robot costs: $50K, $100K initial purchase
($2400 installation, $3000/year maintenance).

Figure 2: *Cost-benefit comparison of DeVAR versus attendant care.*

Acknowledgments

The authors of this paper would like to thank Pacific Gas & Electric Company, RY, and Dr. Inder Perkash for their support and assistance in this study.

References

1. Van der Loos, H.F.M, & Hammel, J. "Designing Rehabilitation Robots as Household Office Equipment". *Proc. of the AI duPont Rehabilitation Robotics Conference,* Wilmington, DE: June, 1990.

Authors' Address

Joy Hammel and Machiel Van der Loos
Palo Alto VA Medical Center
Rehabilitation R&D Center-MS 153
3801 Miranda Avenue
Palo Alto, CA 94304-1200

LOW COST PNEUMATIC ACTUATORS FOR APPLICATIONS IN REHABILITATION ROBOTICS

Stephen D. Prior & Peter R. Warner
Middlesex Polytechnic
Faculty of Engineering, Science & Mathematics
London, United Kingdom.

ABSTRACT

This paper presents the initial results of an investigation into the static and dynamic performance of a new type of low cost pneumatic actuator. The results of the tests will be used to determine the most appropriate actuator for each joint of an electric wheelchair mounted robotic arm. The background to sources of external power is reviewed and the application of flexible pneumatic actuators discussed.

BACKGROUND

The search for alternative methods of actuation has been on-going since the early developments in powered prosthetics/orthotics in the 1950's.
In the early 1960's many research groups focussed on the use of pneumatic servos powered by compressed carbon dioxide CO_2. The essential requirements for any external power source were set out by Kiessling [1] in 1960 and are still valid today, these were:

1. **Universally available.**
2. **Low cost.**
3. **Non toxic.**
4. **Safe in use.**
5. **Ease in Handling.**
6. **Portable.**
7. **High power/weight ratio.**

When CO_2 was reviewed in 1960, as a possible source of external power, it was found to be totally acceptable under all these requirements.
However when developed in practice for the Thalidomide children, problems soon arose. Due to safety requirements, the CO_2 gas bottles had to be filled at a central depot. This meant that each user had to keep several full bottles in storage at their home, with the inevitable cost penalty. The filling costs were also high and the bottles needed replacing often. Another problem was the weight, at approximately 1.5 kg each, they were found to be a portability problem, as described by Davies [2].
For these reasons, more conventional forms of actuation were adopted, notably, electric motors and hydraulic devices.

Pneumatic muscle systems

There have been many different types of muscle actuators designed over the last thirty years. One of the earliest was the McKibben artificial muscle of 1961, which could use either gas or liquid as its working medium. The muscle consisted of a longitudinal piece of hollow braided material, a gas tight inner tube and suitable end fixtures for external attachment and pressurization. When pressurized, the braided material expands and the axial length contracts, so exerting a pulling tension. Recent developments along the same lines include the Bridgestone 'Rubbertuator' (1984) [3], the ROMAC system (1986) [4] and the work by Prof. Jack Winters (1990) [5].

The pneumatic muscle actuator, 'Flexator' described in this work was invented by Mr Jim Hennequin of Inventaid Ltd. The muscle can be used in various different configurations, the current research involves measuring the static and dynamic performance of the 'Flexator' in twenty-four different rotary configurations.
The 'Flexator' is constructed from standard lay-flat fire hose, manufactured in the U.K. for fire fighting applications. The material is light, durable and both heat and water resistant. Its cost is also relatively low (approx. £3 per metre length), it being produced in vast quantities for commercial use.

RESEARCH QUESTIONS

1. Do the 'Flexators' advantages over conventional forms of actuation outweigh its disadvantages.

2. Is it possible to predict the behaviour of the 'Flexator' under varying pressure, temperature, volume and work conditions.

METHOD

The pneumatic muscle actuator is being tested using a purpose-built single-axis test-rig incorporating sensor measurement of shaft position, line and muscle pressure and muscle temperature.

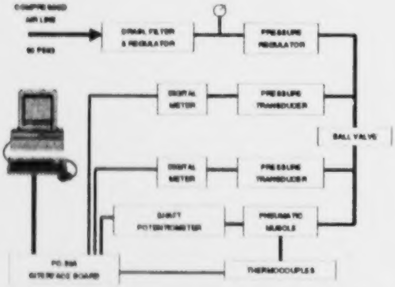


Figure 1.-Schematic layout of the test-rig

Together with the experimental analysis, a theoretical model of the system has been developed using the non-steady flow energy equation (N.S.F.E.E.) incorporating unsteady heat conduction.

EXPERIMENTAL RESULTS

One of the early test results, for a large size of muscle, is shown in Fig.2. From the graph we can see the response of the system to a step input of 40 psig (2.75 bar g) for a single muscle system. After an initial lag of 1.8 seconds the system responds with a linear angular displacement of the output shaft of approximately 180 degrees in 8.5 seconds. We can also notice the pronounced drop in line pressure when the valve is opened. It is planned to investigate the use of accumulators to reduce the pressure drop and the lag of the system. The pressure-line bore diameter and size of the muscle are also critical factors affecting performance.

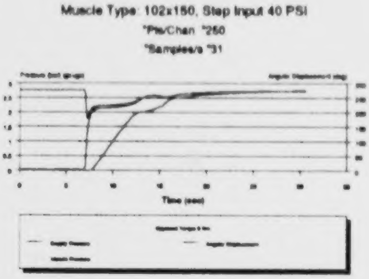


Figure 2.-Response of the system to a step input.

DISCUSSION

Pneumatic muscle actuators like the one described in this paper offer many advantages over conventional forms of actuation. This type of actuation seems to lend itself to the fields of rehabilitation robotics and orthotics/prosthetics, because of its inherent safety and human like quality of compliance. When used in antagonistic pairs they can provide double-acting control together with the ability to vary joint stiffness/compliance independently of joint angle, in a similar manner to human muscles [6].

Whether such systems can be used for industrial robotics remains to be seen.

ACKNOWLEDGEMENTS

The authors would like to thank A.S.P.I.R.E. and NAB for funding this project.

REFERENCES

[1] Kiessling, E.A. (1961) Carbon dioxide as a source of external power for prosthetic devices. *The Application of External Power in Prosthetics & Orthotics*, Appendix E, pp.79-87, Publication 874.

[2] Davies, B.L. (1984) The use of robots to aid the severely disabled. *Electronics & Power*, 3, pp.211-214.

[3] E.P.W. (1984) Rubber muscles take robotics one step further. *Rubber Developments*, vol 37, no.4, pp.117-119.

[4] Immega, G.B. (1986) ROMAC muscle powered robots. *Proceedings of the Robotics Research Conference*, SME technical paper no. MS86-777, pp.1-7.

[5] Winters, J.M. (1990) Braided artificial muscles; mechanical properties and future uses in prosthetics/orthotics. *Proceedings of the 13th Annual Conference, RESNA'90*, pp.173-174.

[6] Mann, R.W. (1990) Agonist-antagonist muscle co-contraction : Ubiquitous but unappreciated. *Proceedings of the 13th Annual Conference, RESNA'90*, pp.57-58.

Stephen D. Prior & Peter R. Warner
Middlesex Polytechnic
Faculty of Engineering, Science & Mathematics
Bounds Green Road
London N11 2NQ
United Kingdom.
Email: Stephen2@uk.ac.mx.cluster

FURTHER DEVELOPMENT OF A ROBOT WORKSTATION FOR THE DISABLED

Graham Pullin *, Michael Hillman +, Andrew Gammie +
Roger Orpwood +, Charles Stammers *
+ Bath Institute of Medical Engineering, United Kingdom
* School of Mechanical Engineering, University of Bath, United Kingdom

Abstract

Following experience with a commercially available arm, a purpose built manipulator has been developed as an integral part of a relatively low cost robotic workstation for the disabled.

Introduction

Robot technology has the potential to provide considerable help to people with severe upper limb disability. The means to manipulate objects would offer a much greater degree of independence than that presently provided by less versatile devices. However systems utilising industrial robot arms are too expensive for the average disabled person to buy.

Background

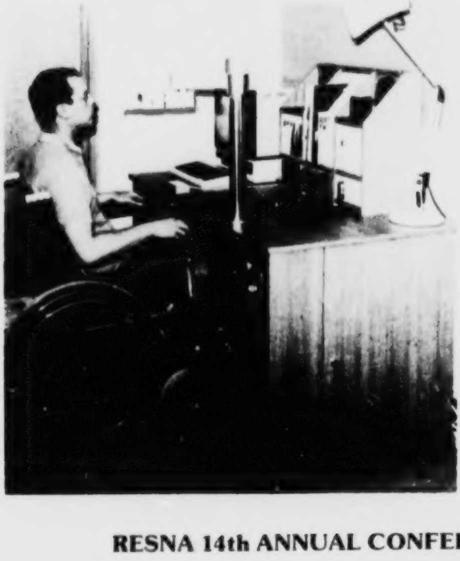
The initial concept of an affordable workstation led to the purchase of a cheap educational robot [1] and the building of a system around it [2]. Clinical trials at a local spinal injuries unit supported the feasibility of a relatively low cost workstation but highlighted fundamental shortcomings of the manipulator employed. Only then was the decision taken to develop our own purpose built robot arm.

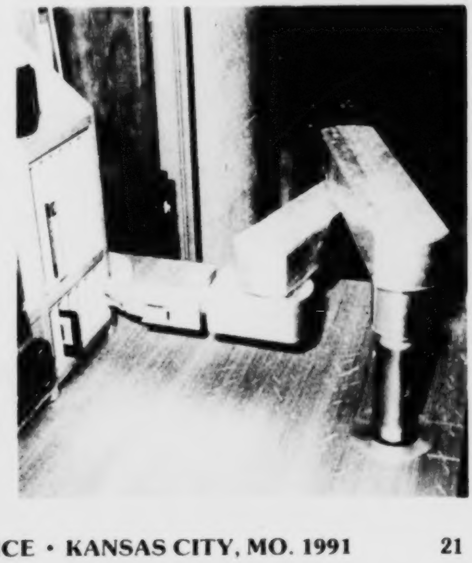
Workstation Layout

To be appropriate in a domestic setting the size of the workstation was reduced to that of a typical desk, 4'6" by 3'. The shelving was integrated into a single unit at the back. It presently contains a computer disc drive, a car radio cassette player and racks for the storage of floppy discs, music tapes, books and documents. The arm is positioned next to the user where it does not obscure the view of the tasks being carried out.

Manipulator Geometry

The manipulator is of a jointed cylindrical geometry. An articulated arm is positioned in the horizontal plane by rotary actuators at shoulder and elbow, whilst vertical motion is provided by a linear actuator which lifts the whole arm. Yaw and roll freedoms are present at the wrist but pitch is omitted because the gripper remains horizontal. The individual link lengths were chosen to allow the arm to fold up into a compact parked position when not in use and the sliding vertical post can be retracted into the desk. The absence of a fixed post allows good visibility along the arm and leads to a less bulky appearance.





Mechanical Design

The lifting mechanism is hidden away in a cabinet under the desk and incorporates a spring to counterbalance the weight of the arm. The rotary actuators do no work against gravity and so are small enough to mount on the arm itself, thereby simplifying the drive train. All joints are driven by geared d.c. servomotors via additional gears or belts. Positional feedback is provided by incremental optical encoders. The hollow arm is constructed from standard aluminium extrusions, all mechanisms and cables being hidden inside.

Control System

The power supplies and electronics are also situated in the cabinet under the desk. A circuit board rack houses a microcomputer accessing six motor control cards and other cards interfacing with sensors on the manipulator. An environmental controller is also included. Software on the microcomputer card controls the movement of the arm, calculating trajectories and passing speed demands to the motor control cards. It also interfaces with a separate desktop computer, with which the user interacts.

User Interface

The computer on the desk is used to display a menu of choices which the user selects with any of a wide range of switching devices. The robot can be controlled directly, or whole routines can be stored and replayed. In addition this computer is still available for programming or word processing.

Wheelchair Mounted Arm

The same basic manipulator could instead be mounted on a wheelchair for increased versatility. It would fold up into a compact parked position behind the seat, keeping it discreetly out of sight when not in use and not increasing the width of the chair. Studies with full scale mock-ups are preceding the construction of a working prototype.

Present Progress

The workstation and manipulator have been built in our workshops by Martin Rouse and Peter Laidler. Electronics and software development is nearing completion. The system has been briefly tested by a multiple sclerosis sufferer and is soon to undergo more extensive clinical trials both at a hospital and in private homes.

Future Work

In anticipation of the results of the trials, different aesthetic treatments of the arm are being examined. Work is also proceeding to refine the basic design to facilitate eventual small batch production. Both considerations favour a change to easily removeable moulded plastic covers around an aluminium structure.

Conclusions

Design and construction of the prototype manipulator and workstation are complete and extensive clinical trials are imminent. The new system overcomes the flaws of the old, which utilised a commercial robot arm. Further refinement is underway to facilitate eventual manufacture. In addition the possibility of mounting the same basic arm on a wheelchair is being considered.

Acknowledgement

Funding for this project was provided by the Wolfson Foundation.

References

(1) Hillman M.R.
A Feasibility Study of a Robot Manipulator for the Disabled
Journal of Medical Engineering and Technology, 11-4, 1987, pp.160-165

(2) Hillman M.R., Pullin G.M., Gammie A.R., Stammers C.W. & Orpwood R.D.
Development of a Robot Arm and Workstation for the Disabled
Journal of Biomedical Engineering, Vol.12, No.3, May 1990, pp.199-204

Graham Pullin
Bath Institute of Medical Engineering
Wolfson Centre
Royal United Hospital
Bath BA1 3NG
United Kingdom

FROM PROTOTYPE TO COMMERCIAL PRODUCT IN SWEDEN

Gunnar Fagerberg[1], Arne Jönsson and Margita Lundman
The Swedish Handicap Institute, Stockholm, Sweden
[1]and INROADS, London, Ontario, Canada

ABSTRACT

This paper describes a Swedish system for facilitating the transfer of prototypes into commercial products. Financial support in different forms can be given to manufacturers. About 15 products are supported annually and more than 60% were subsequently marketed and sold successfully.

BACKGROUND

A well-known problem in rehabilitation technology development is the transfer of development results into manufactured and marketed products. All too often prototypes, even if proven valuable after technical and clinical evaluations, end up on shelves in the laboratory or the workshop. The main reason is that many potential manufacturers regard the market as too small, unknown or uncertain. They are not willing to invest the initial costs for setting up production of a new assistive device.

APPROACH

In order to bridge the gap between prototype and product, the Swedish Handicap Institute, a government agency responsible for the field of rehabilitation technology, supports manufacturers financially at the start of production of a new device for the disabled.

There are two forms of support. A direct subsidy can be given to the company to cover part of intitial costs, such as production adaptation, tools, molds and other set-up costs. The subsidy usually covers 50% or more of the total costs. The Institute has had available 1,5 million SEK (US$ 270,000) per year for these subsidies. The support is combined with a repayment condition: if the product is successful in the marketplace, the company must pay back a percentage of its profit on each product sold.

The Institute can also issue a guarantee that a certain number of products will be sold over a fixed time period, usually two years, from the date marketing starts. If the guaranteed number has not been sold, the Institute will buy the remainder or issue a new guarantee and cover the extra costs for the company. The Institute can have a total maximum of 4 million SEK (US$ 730,000) in outstanding guarantees at any given time.

In their applications for support, manufacturers must include information not only about the product, its characteristics and its user group but also the total costs for production, the intended product price, the number of products to be manufactured and the amount and type of support applied for. This information is handled strictly confidentially.

The decision to give support is based upon an assessment that includes the need of the product, the expected quality of the product, the likelihood of the product not being manufactured without support, the capability of the applicant and if the indicated price is reasonable.

If a decision to grant support is made by the Institute, another agency, SUB, draws up a contract with the applicant, stating in detail the obligations of the company and the conditions for support, including a repayment schedule.

EXPERIENCES

Although the total financial amounts available for the support have been quite small, the program has proved to be successful and valuable. On average, 15 products have been supported annually out of 25 applications. Over the period 1980-85, more than 60% of the products supported were marketed and sold successfully. Some have been exported. Supported products range from ADL equipment to advanced computerbased systems. Examples of products sold internationally are: communication aids Multitalk, PolyCom and PolyTalk, Permobil powered wheelchairs, the Phoenix cane, the Memory Maid hearing aid and the Index Braille printer.

The funds for the support program come from the Ministry of Health. The primary goal of the program is to increase the number of good assistive devices. But the program has also had a positive effect on the assistive technology industry itself. It has clearly helped to create and support the continued existence of new companies in the field of assistive technology. For small companies in particular, this support has been very valuable, or even necessary, for the introduction of new products in their production lines.

The fact that the Handicap Institute shows faith in a potential product by supporting it financially also helps the companies to find other funding, from banks or investors.

In a recent government decision, the annual amount available for support has been increased from 1,5 to 4 million SEK (US$ 720,000), effective from 1991. The support can now also be used to cover the final part of the development phase, in order to bridge the gap between prototype and product even more efficiently.

Gunnar Fagerberg
INROADS
Thames Valley Children's Centre
779 Base Line Road East
London, Ontario
CANADA
N6C 5Y6

3.2 A Follow-up Plan For Rehabilitation Technology: An Occupational Therapist's Role

Paul J. Mortola, MS, OTR, Jean Kohn, MD, Maurice LeBlanc, MSME, CP
Children's Hospital at Stanford,, Rehabilitation Engineering Center,
Palo Alto, CA 94304

ABSTRACT

A follow-up program has been implemented at Children's Hospital at Stanford Rehabilitation Engineering Center to improve the length and the intensity of the care clients receive when they are fitted with rehabilitation technology. The follow-up program, conducted by an occupational therapist, used a three-group experimental design to implement differing levels of follow-up care to 60 subjects. Functional skills and the user/device match were assessed. Preliminary findings from 15 subjects who received a custom seating system suggest that the group who received the highest level of follow-up care were sitting more comfortably, for longer periods, and liked the appearance of their device more when compared to the baseline group.

INTRODUCTION

What currently confronts the rehabilitation technology field is the dilemma of individual needs. How do we as health professionals attempt to mold each piece of technology into the lives of the clients so that they are as functional as possible and the device is produced within the time and monetary constraints that govern our field? To exacerbate these problems, technological advances in the field continue to race forward compounding the problem of identifying what technology is assisting the clients and what technology is adding to the space shortage in the clients' closets. The battle has only begun! It has come time to find out exactly what technology is being used, and by whom? How it is being used? And for how long?

The importance of this issue has not been overlooked by National Institute on Disability and Rehabilitation Research (NIDRR) who in 1978 funded the Children's Hospital at Stanford Rehabilitation Engineering Center (CH@S REC) to conduct research in the area of device effectiveness (Kohn, et al., 1983). In one of the findings cited, the team that conducted 49 home visits out of a total study population of 196, found that 21% of the devices were rated by the team as "limited" or "unsatisfactory". A recommendation from the team was that "Routine follow-up should be staff initiated, at regular intervals; and the cost of the follow-up should be included in the initial cost of the device". As a result of this finding, for the past two years CH@S REC has been conducting additional research in the area of follow-up under a NIDRR funded REC on Technology Transfer. Even though there has been some lag time in the continuation of the follow-up concept it is no coincidence that the opportunity has again presented itself in a period when hospitals and medical facilities are implementing 'across-the-board' quality assurance measures to increase cost-effectiveness and client-satisfaction.

In the past, rehabilitation technology has been delivered with very little, if any, follow-up. If there is going to be an enlightenment concerning our understanding of how the technology is assisting clients, a follow-up plan needs to become one cog in the wheel of the provision and delivery of rehabilitation technology.

What Is Follow-Up? Follow-up in the general market place is not a new concept, but in the medical field, specifically in rehabilitation technology, it is anything but common. A good example of follow-up is the endodontist who has his patients return six months after their initial procedure was completed for a brief, no-charge examination. Why does he do this? There are probably several reasons but the primary motivation being that in the long run it is more cost-effective for him to identify minor problems at the six-month check and correct them rather than have these patients develop major problems down the road costing two to three times as much to repair. When consumers buy a new car costing $10,000 from their local dealer they expect some sort of maintenance program over the next few years or until the car surpasses some designated amount of miles. A consumer who needs to purchase a power wheelchair and a custom-seating system which may cost as much as that new car would find it frustrating to discover that the likelihood of finding such a documented maintenance program for their new piece of rehabilitation technology is highly unlikely. After reviewing the literature available regarding follow-up programs currently being conducted, it would be next to impossible.

Studies by Kohn, Caudrey, Seeger, Coghlan, Law, and McGrath point to one specific and problematic question; how much, if any, follow-up care should providers of rehabilitation technology provide to their clients? Is it enough to call the clients two weeks after they receive the device, or should they be contacted at regular intervals beginning shortly after delivery and continuing through one full year? The Implementation and Follow-up of Rehabilitation Technology program currently being conducted at CH@S REC is using a combination of follow-up techniques to determine how clients can receive maximal benefit from their device and how the REC can provide this service at a cost-effective level.

An Occupational Therapy Role: In a field that is not quite 30 years old, it is hard to identify what a therapist's "traditional role" has been in the provision and delivery of rehabilitation technology. When pressed for a definition, an occupational therapist's role will almost always involve an evaluation component that calls for a decision possibly resulting in the acquisition of rehabilitation technology. Rarely does the occupational therapist function alone in this capacity. Often times the role of the therapist is to work with the team (rehabilitation engineers, physicians, clinicians, physical therapists, technicians, etc.) in deciding the most appropriate technology for the individual. The decisions are not only based on the "want" of the client, but the therapist's and team's knowledge of: assistive technology and the type of devices that are available and/or affordable; the physical, cognitive, and emotional status of the client; and the environmental concerns that can determine the success or failure of a device.

The occupational therapist/project coordinator for the CH@S REC follow-up program is a unique position in the rehabilitation technology field. However, the type of therapy skills that are needed for the position are not reliant on any specialized training but are the basic assessment and evaluation skills that all therapists possess. Whether it is a wheelchair, a seating system, a below-knee prosthesis, or a communication device, the therapist is trained to evaluate and assess the areas that need improvement so that functional gains can be obtained. The 'follow-up' therapist does just that, assess and evaluate the client's functioning with the device. The device alone is not evaluated, the client interface with that device and the environment is. The role of the "follow-up therapist" is to determine the status of the client and their device and to use the evaluational information to determine the action that needs to take place.

METHOD

Group Structure: A total of 60 (N = 60) subjects were entered into the follow-up study during the five-month period in 1989 by randomly assigning the client to the control group (Group 1) or either of the two experimental groups (Group 2 and Group 3). Each of the three groups received a differing amount of follow-up care. Group 1 received the currently practiced follow-up care (baseline) and Groups 2 and 3 received more frequent and intensive follow-up care.

PRELIMINARY RESULTS

The intent of the follow-up program is to determine what types of follow-up are the most effective and efficient during a one-year period. Therefore, partial results will serve only as an example of the type of results that are expected at the conclusion of the one-year study. The six-month results from 15 subjects (five subjects in each of the three groups) who received a custom seating system will be discussed.

- *Device use; Return Visits; Quality of Work; Training Adequacy (Phone -Call Follow-up Form):* At the six-month evaluation only one subject out of Groups 2 and 3 were no longer using their device. Twenty percent in Group 2 and 60% of the subjects in Group 3 had returned to the REC for refittings or adjustments since they received their device six months ago. Ninety percent of the subjects in Groups 2 and 3 rated the quality of work on their new device as "Above Average" or "Excellent". One subject out of ten in Groups 2 and 3 found that the training at the time of delivery was inadequate.

- *Comfort/Appearance (Functional Evaluation Form):* Subjects in Group 3 reported the greatest change in sitting comfort from their old seating systems to their new system. In Group 1, 40% felt that the comfort was "Good" or "Excellent" in their old system while 80% rated their comfort "Good" or "Excellent" in their new system. In Group 3, 100% felt they had greater comfort in the new system when compared to their previous system. When subjects in Group 1 were asked how long they could tolerate sitting in their seating system each day, 40% could sit for six hours or more in their old system while 60% could sit in their new systems for the same length of time. Eighty percent of the subjects in Group 2 and 100% of the subjects in Group 3 were able to sit for eight or more hours in their new systems. Both these figures were greater than the subjects sitting tolerance in their old system. When asked if the devices appearance was acceptable, only the subjects in Group 3 were all satisfied with their new devices appearance.

DISCUSSION

The findings discussed in the results section are incomplete and preliminary. Even with this premature analysis there are obvious trends that favor the subjects in Group 3. The fact that a subject was in Group 1, 2 or 3 did not alter , in any way, the recommendation or selection of a particular device. Yet, the preliminary results show that subjects in Group 3 are more comfortable, are able to tolerate sitting longer, and like the appearance of the device better than the subjects in Group 1 and, to a lesser degree, the subjects in Group 2. How can this be explained? The full impact of follow-up can not be realized until this study and others of a similar scope are analyzed. For now, it can be assumed that since the subjects in Group 3 were seen at the REC for additional work (following the initial delivery) on a significantly more frequent basis, their device has a better "fit" than those subjects who have had no additional visits.

The role of the occupational therapist in the follow-up program can be a natural extension of the evaluation and assessment skills possessed by all therapists. Rehabilitation technology can be divided into two areas: "low technology" which commonly is associated with "off the shelf" products that are usually not customized (i.e., reachers, button assists, etc.); and "high technology" which is customized and tends to be "one-of-a-kind" equipment that require evaluation and fabrication components. Although these devices vary somewhat, the critical need for an accurate evaluation, training, and follow-up can play a significant role in the eventual acceptance of the device.

Although follow-up is by no means a routine practice in the field of rehabilitation technology, occupational therapists are well suited to functionally assess the match of technology with the needs of the users.

REFERENCES

Caudrey D. J., Seeger, B.R.: Rehabilitation Engineering Service Evaluation: A Follow-Up Survey of Device Effectiveness and Patient Acceptance. Rehab Lit 44:80-84, 1983.

Coghlan, J.K., Robinson, C.E., Newmarch, B., Jackson, G.: Lower Extremity Bracing in Paraplegia - A Follow-Up Study: Paraplegia, 18(25-32), 1980.

Kohn, J. Enders, S., Preston, J. Motloch, W.: Provision of Assistive Equipment for Handicapped Persons. Arch Phs Med and Rehabl 64(378-381), 1983.

Law, D.F.: Measuring the Benefits of Technology in the Rehab Setting - A Commentary from The Service Provider's Perspective. Proceedings of RESNA 10th Annual Conference, San Jose, CA, 1987.

McGrath P.J., Goodman, J.T., Cunningham, S.J., MacDonald, B.J.k Nichols, T.A., Unruh, A: Assistive devices: Utilization by Children. Arch Phys Med Rehabil 66:430-432, 1985.

Mortola, P.J., Kohn, J., LeBlanc, M.: Follow-up and Videotape in Rehabilitation Technology. Proceedings of RESNA 13th Annual Conference, Washington, D.C., 1990.

Management of Spasticity Via Electrically Operated Force Relecting Sticks

Daniel W. Repperger
Armstrong Aerospace Medical Research Laboratory
Wright Patterson Air Force Base, Ohio 45433-6573

Introduction:

At the Armstrong Aerospace Medical Research Laboratory, Wright Patterson Air Force Base, Ohio, recent Department of Defense (DoD) studies have investigated force reflecting stick controllers which assist pilots in removing extraneous responses in their stick motions. These types of extraneous arm motions are a consequence of a pilot flying an aircraft in a complex acceleration environment. This same type of technology developed in the DoD can be easily transferred to studies in Rehabilitation Engineering involving spastic patients. The objective of this study is to obtain better stick controllers which preclude or better manage spasticity. A joint effort is being initiated between the VA/DoD with application to head trauma patients at the VA in Hines, Illinois. The two most obvious uses of this technology are: (1) Design of spastic free wheelchair stick controllers, (2) Design of stick controllers for input devices into computers as communication aids.

Methods:

The device constructed for this effort was constrained to be completely electrically operated. It was required to use minimum electric power, it must operate in two axes with force reflection occurring in both axes simultaneously, and the device must have minimum weight and size. The force reflection developed by this system must only penalize spastic arm motions. Normal stick displacement motions for control of a device such as a wheelchair must not physiologically fatigue the user. Thus the device must recognize the difference between a spasm and a normal stick motion in order to apply force reflection at the appropriate time.

Results:

A two axes, force reflecting stick prototype has been built which can act (electrically) as a pure dashpot, or a pure spring, or any hybrid combination of these mechanical characteristics. The method of distinguishing between a spasm and a normal stick input is developed in electrical hardware. This circuit is developed on a small testboard and can easily be converted to a chip. The overall device produces up to 4.8 foot-pounds of torque and its size is quite manageable for wheelchair applications because it fits in a reasonably small volume. The electric operation of this device is such that when no spasm occurs, no power is withdrawn from the battery. Therefore it is an apparently subtle device which only operates during a spasm. The testbed developed for this study is to be used to collect data and to illustrate the efficacy of force reflection to better manage spasticity. Testing of patients with spasticity will commence in the summer of 1991.

Discussion:

The technology developed in aircraft stick controllers to remove undesirable biodynamic responses can be transferred to studies dealing with the management of spasticity. The convenience of using electrical devices results in a small testbed that is amenable to studies in Rehabilitation Engineering. By having such a device which is constrained to minimize the electric power drained from a source such as a wheelchair battery, this technology becomes attractive for use in Rehabilitation Engineering. The remaining constraints such as size, weight, and torque output make the engineering design of such a device a technology breakthrough for those people who need assistive aids to help manage spasticity. The prototype developed by the DoD will be demonstrated at the RESNA Conference.

3.4

Low Vision - The Reference - A Case Study of Using Disk Media to Disseminate Bibliographic Information

David L. Jaffe - Rehabilitation Research & Development Center
Gregory L. Goodrich - Western Blind Rehabilitation Center
Department of Veterans Affairs Medical Center - Palo Alto, CA

Abstract

Low Vision - The Reference is a computer disk-based compilation of over 3700 citations of books, journal articles, conference proceedings, and other works on the broad topic of low vision. It covers the areas of rehabilitation, optometry, psychology, ophthalmology, visual science, and education.

Providing this information on a disk enhances its utility over the personal compilation traditionally employed by researchers. It is easier to update and distribute and it can be used with a variety of computer systems and database programs. In addition, it is accessible to low vision and blind researchers through the use of adaptive hardware and software.

Background

In 1985, Dr. Olga Overbury, then a post-doctoral fellow at the Western Blind Rehabilitation Center (WBRC) at the Palo Alto VA Medical Center, began accumulating a low vision reference list. The compilation soon contained several hundred citations. In 1986, the list was distributed as a handout at the First California International Low Vision Conference held in Asilomar, CA. When Dr. Overbury completed her fellowship, the reference list was taken over by one of us (Goodrich). By 1989, it had grown to over 1000 entries. Although frequently used by its authors, few researchers in the field knew of the reference's existence.

In the intervening years, the reference became more comprehensive by incorporating bibliographies compiled by Hilda Caton, Marrianne May, and other colleagues at the WBRC. Reference lists from publications and computer literature searches were also added.

Objective

Several suggestions were considered as ways to improve researcher's access to the low vision literature. First, a comprehensive reference would be desirable. Second, a keyword index would make locating references easier. Third, a text document would be cumbersome to search compared with a disk-based version. Fourth, both Macintosh and IBM PC disk formats of the reference would have to be available. Fifth, generic file formats would make the reference compatible with a variety of commercial database application programs. Finally, dissemination on a computer disk would allow the greatest flexibility in modifying the data. An approach meeting all these requirements would give any user with a personal computer easy access to a versatile and comprehensive database of the low vision literature.

Method / Approach

Low Vision - The Reference, a compilation of low vision citations, has been developed on computer disk media as an improvement over the traditional publication of this bibliographic information in print form. A print version would be bulky (over 400 pages) and inaccessible to users with low vision or blindness. Since the average number of publications per year in low vision has doubled each decade since 1950 (see Figure 1), a text document would soon become obsolete. On the positive side, the disk format offers many important benefits. The entire reference can be stored onto one standard 3.5 inch floppy diskette which is easier to update, duplicate, and disseminate than a bound print volume. The disk media version of the reference is compatible with both Macintosh and PC computers. The information on the disk is stored as database files that are easily searched and sorted to find entries that meet certain criteria. For example, all references of a particular author or citations covering a specific topic like color vision can be retrieved. Finally, the computer version can be made accessible to low vision and blind database users by using various large print and voice output adaptions to computer systems.

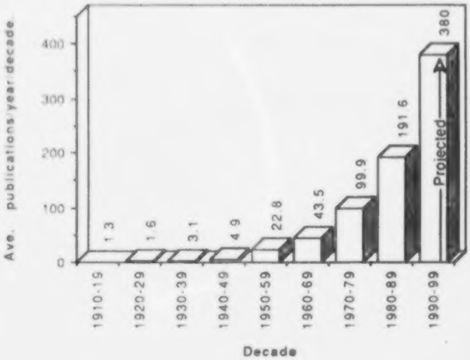


Figure 1 - The number of low vision publications per year by decade.

The Macintosh version of *Low Vision - The Reference* was created using FileMaker (Claris Corp.) and requires one megabyte of RAM and 1.5 megabytes of hard disk space. This version is also accessible with Macintosh compatible database software that accepts tab delimited text fields and recognizes records separated by a carriage return.

The PC compatible version of *Low Vision - The Reference* is identical in content to the Macintosh version and is stored in a dBase (Ashton-Tate) compatible format. One of several dBase-compatible software packages is required to use the database. For ease of dissemination, the files on the PC compatible disk have been compressed to fit onto one 3.5 inch 720K floppy disk. During installation, the files are decompressed and moved to the hard disk where they occupy 3 megabytes.

These text/dBase file compatibility formats have wide acceptance and allow users considerable freedom in their choice of database software. Therefore, the purchase of a specific commercial database program is not required.

As illustrated in the sample record below, each citation in *Low Vision - The Reference*, is composed of five fields: author, date of publication, title, source, and keyword index. Each of these fields can be searched to find the citations that meet the researcher's needs.

Sample Record:

Busse, D.G., Romer, L.R., Fewell, R.R. & Vadasy, P.F.
(1985).
Employment of deaf-blind Rubella students in a subsidized work program.
Journal of Visual Impairment and Blindness, 79 (2), 59-64.
MULTIPLE HANDICAPS, VOCATIONS, LEARNING SKILLS AND DEVELOPMENT, RUBELLA

The keyword index field was added to each citation as another method of sorting and selecting references. The 81 keywords are organized in the following major categories: AGING including CHILDREN (under 18 and including infants), CHILDHOOD DEVELOPMENT (motor and personality development), and LEARNING SKILLS AND DISABILITIES (including cognitive skills), DEVICES (13 areas including general vision correction, evaluation, and technological studies), EDUCATION (4 areas including school settings), EYE DISEASES & DISORDERS (32 areas), EYE SURGERY (including all surgeries), FAMILY ISSUES (including involvement and counseling), LIGHTING (including light and illumination studies), LOW VISION SERVICES (2 areas including delivery, organization, management, and evaluation of clinics, departments, or agencies), PERCEPTION (11 areas including tests of vision), PERCEPTUAL SKILLS AND TRAINING (5 areas including utilization studies, rehabilitation, and eye exercises), SOCIETAL CONSIDERATIONS (including social and economic costs of vision disorders), and STATISTICAL STUDIES (including demographics, epidemiology, and case studies of over 250 subjects).

The disk versions are accessible with some large print and synthetic voice access programs. *Low Vision - The Reference* has been successfully used in the Macintosh environment with CloseView and Outspoken with the FileMaker database application program. In the PC version, dBase databases have been tested with JAWS, VERT, and Artic Vision speech synthesizers.

Coburn Optical Industries provided a grant to support the citation entry, keyword indexing, and proofreading tasks necessary to make this reference available in a highly useful form to researchers around the world.

Both the Macintosh and PC versions of the database are available from:

Low Vision Center of Tulsa
Autumn Oaks Building
6846 South Canton Ave., Suite 130
Tulsa, OK 74136
918/494-6000
918/494-0175 FAX

Discussion

Low Vision - The Reference was first made available in December, 1990 through Coburn Optical Industries and has been advertised through LOVNET, an organization of low vision investigators with electronic mail accounts on Internet. As of this writing, several dozen orders have been placed with Coburn. An evaluation of the reference, its ease of installation and use is planned by the authors.

As demand warrants, updates will be made available on computer disk.

Reference

Goodrich, G.L. and Jose, R.T. (1990). The Low Vision Literature and *Low Vision - The Reference*. *Journal of Vision Rehabilitation*, 4 (3), 27-34.

Acknowledgements

Low Vision- The Reference was developed at the Western Blind Rehabilitation Center at the Veterans Administration Medical Center in Palo Alto, CA and the Low Vision Center of Tulsa, OK with a grant from Coburn Optical Industries.

Authors

David L. Jaffe
Rehabilitation Research & Development Center
Palo Alto VA Medical Center
3801 Miranda Ave., Mail Stop 153
Palo Alto, CA 94304

Gregory L. Goodrich
Western Blind Rehabilitation Center
Palo Alto VA Medical Center
3801 Miranda Ave., Mail Stop 124
Palo Alto, CA 94304

3.5

An Interdisciplinary Approach to Product Assessment

Kitch Barnicle[1] & Chris Lavanchy[2]
[1]National Rehabilitation Hospital, Washington, D.C.
[2]ECRI, Plymouth Meeting, PA

ABSTRACT

Several classes of rehabilitation equipment were evaluated by an interdisciplinary team including occupational therapists, physical therapists, biomedical, and mechanical engineers. The results of performance evaluations, clinical assessments as well as input from additional clinical experts and users were combined to create comprehensive reports reviewing selected assistive technology. Five classes of products have been or are currently being evaluated by the team of clinicians and engineers. The results of these evaluations can help individuals make the appropriate, critical match between the user and the device.

BACKGROUND

Choosing or prescribing assistive technology can be a difficult task. Many factors which are unique to each potential user must be considered prior to selecting a device, such as current physical status, prognosis and the home or work environment. The significance of the decision to purchase a piece of adaptive technology increases when cost and reimbursement issues are considered. In many instances a third party payor will only reimburse a consumer for a single device and if a poor selection is made the user is often left without further alternatives. Adding to the dilemma is the sometimes large number of devices available within a class of products. The consumer often does not have the resources available to determine which device, will work effectively and efficiently to meet their needs, is reliable, safe, easy to use as well as affordable. [Galvin, 90] Consumers and clinicians must make the decision to buy or prescribe rehabilitation products based on information provided by the manufacturer and or product vendor. In many rehabilitation centers only a limited number of devices are available for trial use. The purchase of a piece of equipment can represent a significant expenditure for an individual, family or third party payor. The consequences of a poor match between an assistive technology user and device can range from device abandonment with a subsequent decrease in independence to serious medical complications. [Batavia,90]

APPROACH

Evaluating assistive technology requires several steps and input from representatives of many disciplines. The evaluation process combines two distinct methods of analysis, engineering and clinical analyses. Many human factor, ease of use and safety features of the devices under test are evaluated from both an engineering and clinical perspective. Throughout the process of evaluating assistive devices the findings of the engineering and clinical analyses have a great influence on each other. The preliminary results of performance testing may result in a redirection or updating of the clinical assessment. Likewise an unexpected finding during a clinical assessment may suggest the need for additional performance testing. Below is a description of the testing conducted during a product evaluation. Though discussed separately here, the successful integration of results is important in the development of a product evaluation.

Performance Testing

Prior to testing products, research is conducted to determine the existence of previously established United States or international standards. Performance criteria are created using existing standards. If no standard for the device has been established performance criteria are adapted from criteria for similar devices or are based on the perception of need derived from extensive product research. Performance analysis can encompass a wide range of tests depending upon the complexity and intended use of a device.

Product evaluation involves examining three central aspects of the product, its performance, safety and ease of use. The evaluation begins by examining certain basic criteria such as stability, load capacity, electrical and/or mechanical safety and quality of construction and design. Additional product specific tests are also performed, such as the maneuverability of scooters or slip resistance of canes (see table 1). Performance tests are developed to reflect actual use situations. Device testing is conducted at an independent test laboratory.

Clinical Assessment
In addition to the extensive performance testing, each product evaluated undergoes a clinical assessment. Occupational therapists, physical therapists and rehabilitation engineers assess the device to determine its functional effectiveness. These assessments are based on an analysis of how the device will be used, the clinicians experience with the device, published reports and interviews with users. The clinical assessments are conducted in order to determine how individuals with various disabilities will function with a particular device. For example, an individual with arthritis may find a comfortable scooter handle valuable while an individual who may have difficulty transferring may find a swivel seat more important than the handle type.

The clinical and engineering analyses of the products are carefully merged to create a document that is clear and easy to read. Throughout the evaluation process the test methods, procedure and documentation undergo extensive review by experienced engineers, clinicians, manufacturers and consumers [Brown, 90]. Efforts are made to ensure that the final report is both accurate and understandable. The final document is disseminated to consumers, manufacturers, clinicians and third party payors.

Results
Five classes of devices have been or are currently being evaluated (see table 1). The last column represents the percentage of devices that were rated acceptable, followed by the total percentage rated acceptable or conditionally acceptable. In other words almost all of the devices tested are acceptable for use but many only under certain conditions. For example, virtually all of the canes evaluated met the established criteria, however, many were rated conditionally acceptable and should not be used by individuals weighing over 230 pounds due to their inability to withstand potential high impact loads. [REquest,90 Canes Crut[illegible] & Walkers]

PRODUCT	#	TEST CATEGORY	% Rated** Acceptable
Patient Transfer Aids ·rotating disks ·slings ·transfer boards ·transfer stands	5	·weight capacity ·wear resistance ·surface texture ·weight ·user comfort ·ease of use ·quality of construction ·safety ·ease of cleaning	40% / 80%
Patient Lifts	15	·strength ·stability ·tendency to swing ·quality of construction and design ·fluid spill ·ease of use ·mechanical efficiency	60% / 100%
Canes Crutches Walkers	26 19 22	·static loading ·dynamic loading ·slip resistance ·stability ·ease of adjustment ·quality of construction and design	Canes 54% / 100% Crutches 100% / 100% Walkers 73% / 100%
Scooters*	17?	·maneuverability ·stability ·range ·handling ·general safety	Scooters not rated
Batteries* ·gel cell ·sealed cell ·wet cell	14 8 2 4	·capacity ·life time	Batteries not rated

* These products currently being evaluated, results are preliminary

** Percentage rated acceptable / percentage rated acceptable or conditionally acceptable

Though most devices passed the performance tests, the accompanying clinical assessment indicates that certain devices may not be appropriate for many individuals. For example, one transfer aid was rated conditionally acceptable; it passed the test criteria. However, the device should not be used by individuals with a breathing impairment because the unit may cause chest compression or dislodge ventilator tubes [REquest 90].

DISCUSSION

Because individuals with a variety of functional limitations may be purchasing and using the same device it is important that these individuals assess their own needs and environment. This is particularly true of first time buyers who may not be aware of all of their needs. The importance of having both engineering and clinical analyses of a device becomes apparent during the process of product selection. Combining the results of the evaluation in one document will help potential buyers or users determine what type of features and characteristics will meet their needs.

The collaborative procedure of evaluating assistive technology developed at the REC, and the independent testing laboratory, was designed to assist consumers and clinicians with the process of selecting the most appropriate assistive technology. The reports produced are also intended to assist third party payors make reimbursement decisions. In addition, the product evaluations provide important feedback to manufacturers and equipment dealers as to how their device performed relative to its competitors and which features were considered valuable or detrimental to the effective use of the device.

Further work is needed to encourage the medical, rehabilitation, and manufacturing communities to develop product standards and evaluation procedures for all assistive technology.

ACKNOWLEDGEMENTS

This work supported by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant no. H-133E80016.

REFERENCES

Batavia, A., Dillard, D., Phillips, B.:How to Avoid Technology Abandonment. Proc. 5th Annual Technology and Persons with Disabilities,'p. 55 Los Angeles, March 1990.

Brown, K., Lavanchy, C.: Evaluation of Rehabilitation Devices: A Practical Example. Proc 13th Annual RESNA, June 1990, p.27, Washington DC.

Galvin, J.,: Evaluation of Assistive Technology. STAR Research and Development Forum, Plymouth, MN, May 23, 1990.

REquest Rehabilitation Engineering Center. (1989) Evaluation of patient transfer aids. Washington DC.

REquest Rehabilitation Engineering Center. (1990) Evaluation of canes, crutches and walkers. Washington DC.

REquest Rehabilitation Engineering Center. (1990) Evaluation of patient lifts. Washington, DC.

Kitch Barnicle
National Rehabilitation Hospital
Rehabilitation Engineering Center
102 Irving St. NW
Washington, DC 20010-2949

TECHNOLOGY TRANSFER THROUGH STUDENT DESIGN PROJECTS

Allen H. Hoffman and Holly K. Ault
Mechanical Engineering Department
Worcester Polytechnic Institute

ABSTRACT

Engineering student projects which design and construct devices to aid the handicapped are a unique mode of technology transfer. Advantages of this mode of technology transfer are direct interaction between the user and the design team, the creation of unique custom designs at minimal cost, and the ability of the design team to utilize the technical expertise and resources of a multidisciplinary university. Disadvantages are long lead times, inexperience of the design team, variable workmanship, and the lack of design improvements fostered by a long term relation between the user and the design team. Several examples of devices designed by student teams are presented.

BACKGROUND

Handicapped individuals often require customized assist devices to meet their special needs. Currently there is little infrastructure to deliver services for the design and construction of highly individualized devices at reasonable cost. Thus, the need for very specialized equipment is often not fulfilled. For less unique needs, a typical approach is to take a standardized device and attempt to modify it. Often these modifications are of an "ad hoc" nature and the outcome depends solely on the skill of the person performing the modifications. Furthermore, the private sector is often not interested in producing devices which may be desirable but are not required, such as recreational sports devices. Overall there exists a void in the delivery of customized assist devices to users. Student projects are an opportunity to focus the combined resources of the university and rehabilitation center on the solution of specific problems. The value of this mode of technology transfer has been recognized by both rehabilitation centers (1) and the National Science Foundation (2).

OBJECTIVE

We and our students have undertaken a series of student design projects which attempt to meet the needs of individual users. The features incorporated into these individualized devices often have wider application among groups of users.

METHOD/APPROACH

Our institution requires that all students complete a major (design) project during their senior year. To generate projects, we have developed long term relationships with several rehabilitation facilities. Professionals (i.e. engineers, occupational therapists, etc.) at these facilities develop written descriptions for potential projects and agree to serve as off-campus liaisons for the project if it is selected by the student teams. The project descriptions are used to recruit students. More projects are suggested than can be implemented. The faculty decide how many student project teams, each containing 2-4 students, we will advise. There is considerable student interest in rehabilitation design projects and we have found it necessary to select among the student applicants. The students then form their own design teams and select their specific projects. The project liaison acts as the interface between the faculty/students and the user. A primary requirement for successful completion of the project is the design, construction and delivery of a working device (or model if that was the objective). Faculty meet with the student teams on at least a weekly basis, while meetings are held with the liaison and/or user on approximately a monthly basis. Telephone/mail contact is more frequent. Direct costs associated with the design projects are primarily for construction materials. These costs have been offset by donations of materials from the rehabilitation centers, manufacturers, the college and more recently by a modest budget from NSF under the BRAD program. Examples of design projects are presented in the results.

RESULTS

Among recently completed projects is the design of a mechanism to allow a quadraplegic to row a boat more efficiently. The design used the force exerted by the rower against the back of the seat to move the oarlock relative to the seat position and thereby improve the efficiency. A model of the mechanism was built.

A user operated wheelchair lift was designed and built to facilitate transfers between a bed and a wheelchair. A hand operated hydraulic piston powered the device and incorporated a unique safety mechanism to prevent the wheelchair from rolling off the lift. In another project, a standing device was constructed to enable a paraplegic to participate in sports activities such as golf and baseball batting (Figure 1). Current projects involve the design and construction of a powered personal mobility device for a young child (age 3-6) and the design and construction of a lightweight sports wheelchair frame.

DISCUSSION

The direct and continuing interaction between the design team, rehabilitation professional and user enhances the likelihood of a successful device. Frequent contact is essential to ensure that the device meets the user's needs. In our experience, the students tend to become very committed to developing a successful device and no longer view the project as purely an academic exercise. From an expense standpoint, only the direct cost of materials needs to be covered. Project advising is part of the faculty's normal work load. Our institution prohibits payment of salaries to undergraduates when academic credit is earned. Since student projects are required, the university expects to commit a modest amount of resources to this activity. The students have access to the expertise and facilities of the entire university. This includes out-of-department faculty, shops, library and computer facilities. Similarly the students have access to the rehabilitation center data bases, personnel and expertise. In effect, the student design team becomes a vehicle for transferring technology between the university, the rehabilitation center and the user. This approach is well suited to designing devices for unique applications which require interdisciplinary expertise.

An additional benefit is that engineering students are exposed to real problems in the rehabilitation field. This exposure often changes their view of the disabled and for some students, it influences their career path.

There are some disadvantages to this approach. The process is slow and thus not suited to meeting the immediate needs of the user. Generally it takes one year or more from when a project is first proposed until it is completed. Student teams are inexperienced in the design process and thus project initiation time is extensive. Major portions of the devices are student produced and workmanship can be variable when compared to a professionally manufactured product. However, the devices are functional and in some cases would not have been produced in any other manner. Usually there is insufficient time remaining after the initial device has been produced, to modify it, and develop an improved second generation device. The rehabilitation facility may not have the resources or time to further improve the device.

In summary, student design projects offer a unique method for the transfer of technology from a university environment to the rehabilitation community. Custom devices are created at minimal cost. Direct and continuing interaction between the design team, rehabilitation professional, and user is necessary to assure a successful outcome.

REFERENCES

1. Brockman, R.T, "Public and Private Resources: Discovering an Open Ear to Implementing Services", Proceedings of the 12th RESNA Conference, 329-330, 1989.

2. Enderle, J.D., "National Science Foundation 1989 Engineering Senior Design Projects to Aid the Disabled", NDSU Press, Fargo, ND, 1989.

ACKNOWLEDGEMENTS

A portion of this work was supported by NSF BRAD Grant # BCS-8907759. The cooperation of the Massachusetts Hospital School is gratefully acknowledged.

Prof. Allen H. Hoffman
Mechanical Engineering Department
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

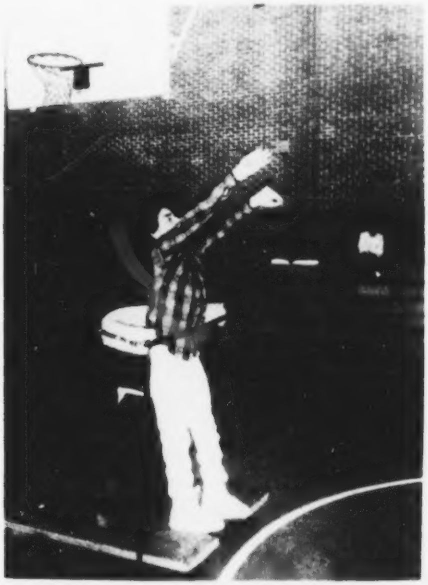


Figure 1. Sports Standing Device

3.7

Using the Knowledge of Human Factors Engineering in Rehabilitation Services

James A. Boyless, P.E.
Department of Special Education and Rehabilitation
University of Arizona
Tucson, Arizona USA

Introduction

Rehabilitation professionals have the opportunity to lessen the impact of a disabling condition by proscribing assistive technology devices. The application of assistive technology holds great promise for enriching educational opportunities, improving independent living options, equalizing employment opportunities, and expanding leisure skills for persons with disabilities (Barker, 1990). There remains, however, general agreement that the services required to properly match clients' abilities with appropriate equipment options, and to provide the equipment usage training across environments, are still fragmented (Barker).

Discussion

Fragmentation of the required services in rehabilitation exists because assistive technology, when applied to assistive devices in rehabilitation, is haphazard, misapplied, misunderstood, and mismatched. Haphazard application of assistive technology is the result of buying an off-the-shelf item and expecting it to work without evaluation. Misapplication occurs when more technology is thought to be better than appropriate technology. Misunderstanding is the result of of simply being unaware of what assistive technology is available. Finally, the client can be mismatched with assistive technology beyond his/her capabilities, limitations, and needs. Applying human factors engineering principles to the system combination of client and assistive technology can eliminate or drastically reduce fragmentation in the rehabilitation system.

Both the rehabilitation system and the human factors engineering discipline have as a central focus: the client. Rehabilitation professionals attempt to restore their clients to that client's maximum potential, perhaps using assistive technology, while human factors engineering specialists design and evaluate systems to enhance effectiveness and efficiency for the client.

Human factored designed and evaluated systems are composed of human, machines, and other items coupled together in one place, at one time, interacting to reach a goal that could not be reached ***independently*** (my emphasis) by these same components Bailey (1982). The key word is ***independently***. It appears that rehabilitative personnel in the system are acting independently rather than personnel in a system united in its effort to support the client.

By acting independently individuals within the rehabilitative system depart from its intended mission of client support, resulting in fragmentation. The author does not imply that acting independently is inappropriate but rather to emphasize that rehabilitative personnel in the rehabilitation system must have a focal point that provides relevant information on assistive technology and its application to the needs of the client.

The focal point, in the rehabilitation system for assistive technology application, should be the rehabilitation engineer cognizant of human factors engineering principles. Rehabilitation engineering professionals combine an interdisciplinary study of engineering, liberal arts, science, and education. Rehabilitation engineers take supported courses in psychology, sociology, physiology, special education, and rehabilitation that enhance the understanding of human abilities, limitations, and needs. The education of rehabilitation engineers does not end with graduation, but through continual study these professionals remain updated on new approaches, techniques, and equipment to match clients with the appropriate technology. One area of study for the rehabilitation engineer includes human factors engineering.

Human Factors Engineering

Human factors engineering or human factors, in simple terms, means designing for human use. The definition of human factors is based in terms of focus, objectives, and approach. Human factors specialists focus on human beings and their interaction with products, equipment, facilities, procedures, and environments used in work and everyday living to better match the capabilities, limitations, and needs of people. The two major objectives of human factors are a) to enhance the effectiveness and efficiency with which work and other activities are carried out and b) to enhance certain desirable human values. Human factors engineering specialists approach design and evaluation through the systematic application of relevant information about human capabilities, limitations, characteristics, behavior, and motivation. This definition lays the foundation for the fundamental concept in this discipline.

The fundamental concept in human factors engineering is the *system*. Restating Bailey (1982), a system is an entity that exists to carry out some purpose. Systems are composed of humans, machines, and other items coupled together in one place, at one time interact to reach a goal that could not be reached independently by these same components. Human-machine systems are combinations of one or more human beings and one or more physical components interacting to bring about, from given inputs, some desired output Sanders (1987). Human-machine systems include manual systems, mechanical systems, and automated systems. Manual systems consist of tools and other aids. Mechanical or semiautomatic systems consist of well-integrated physical parts that are generally designed to perform their functions with little variation. Automated systems perform all operational functions with little or no intervention once activated. Each system requires various levels of human control and levels of technology.

Control of the system is accomplished through the human-machine interface. The human-machine interface is the most important portion of the system. Through the interface, the individual receives information in order to activate, respond, control, or deactivate the system. Information may be presented to the client through visual, auditory, and tactile displays or through speech communication. The human-machine interface is crucial to the intended goal of the system. If designed correctly, the human-machine interface aids in reaching the system goal and client satisfaction. Client satisfaction increases effectiveness and efficiency while at the same time reduces stress and fatigue in work and other activities. Satisfaction also means a successful system design.

The successful system design results from the human factors engineering process. Given the goal of a desired system, the human factors engineering specialists formulate a design to meet that goal by applying relevant information about the capabilities, limitations, and needs of the client, matching appropriate equipment options, and integrating a human-machine interface for positive flow of information.

Conclusion

With a focal point for technology, the rehabilitation system can overcome fragmentation from independent application of assistive technology that is often haphazard, misapplied, misunderstood and mismatched for the client. The client will derive maximum benefits from the appropriate assistive device designed and evaluated under appropriate human factors engineering principles. Finally, clients will benefit from desirable human values including increased comfort, reduced fatigue and stress, and greater satisfaction.

References

1. Barker, L.K. (1990). Private Practice: A Successful Approach to Assistive Technology Service Delivery. *OSER News in Print!* Vol III, No 2, (pp 16-18).
2. Bailey, R. (1982). *Human Performance Engineering: A Guide for System Engineers*. Englewood Cliffs, NJ: Prentice-Hall.
3. Sanders, M.S. & McCormick, E.J. (1987). *Human Factors in Engineering and Design*. New York: McGraw-Hill.

James A. Boyless, P.E.
Department of Special Education
and Rehabilitation
University of Arizona
Tucson, Arizona 85721

4.1

Intelligibility Experiments with a Feature Extraction System Designed to Simulate a Low-Bandwidth Video Telephone for Deaf People

Judith E. Harkins, Ph.D., Anthony B. Wolff, Ph.D., and Elizabeth Korres
Gallaudet University

Richard A. Foulds, Ph.D. and Scott Galuska, M.S.
A. I. du Pont Institute/University of Delaware

INTRODUCTION

This paper describes experiments to evaluate an algorithm for extraction of features from video images of individuals producing signs and fingerspelling. The experiment assessed the intelligibility of off-line processed images presented at four frame rates.

A system developed at the University of Delaware/A. I. du Pont Institute was evaluated through intelligibility tests by researchers at Gallaudet University.

In order to develop a way for deaf individuals to communicate over ordinary residential telephone lines by signing, methods must be developed to severely compress the amount of data found in full video, such that the information may be transmitted in real-time. The method chosen by for this study is the extraction of important features of a signer, such as hands, torso and facial features, using a sophisticated 5 x 5 pixel valley-detection operator developed by Pearson and Robinson (Pearson and Robinson, 1985). After further development, the feature extracted images could then be transmitted over a phone line and animated on the receiving end.

Two questions were addressed regarding the technical feasibility of transmission over a telephone. First, could the computer perform the feature-extraction quickly enough to achieve real-time conversation? By using parallel processors called transputers mounted inside a PC, video could be processed at a rate of 7.5 to 9.0 frames per second (fps) with a spatial resolution of 256 x 256 pixels (Galuska, 1990). These images could then be animated at a rate of 30 fps by processing every third or fourth video frame in succession.

Regarding the intelligibility and acceptability of the images to the intended users, many questions are raised. The most obvious question is whether the processed images produce signs and fingerspelling that are intelligible, and what frame rates are necessary for intelligibility. Another question is whether signers are willing to adjust their signing to compensate for weaknesses in the system; for example, will singers willingly slow their fingerspelling for reasons of enhancing intelligibility? The first questions are addressed in this experiment and the second questions will be evaluated when a real-time system is completed in 1991.

METHOD

Once the feature extraction algorithm was devised, four frame rates were selected for evaluation. Thirty fps was chosen because of its value in comparison with the control condition of full-video, which also is presented at 30 fps. The rates of 10, 7.5, and 6 fps were chosen because of the possibility to reduce the data transmission requirement by factors of 3, 4, and 5, respectively.

Preparation of Stimuli

The stimuli were videotaped using a commercially available VHs video camcorder at a rate of 30 fps and a shutter speed of 1/500 second. The signers wore solid, dark clothing and were videotaped against a solid black background in order to achieve the greatest amount of contrast between the skin tone and the background. This is important for the feature extraction process to yield images that retain important information (such as hand shape) while eliminating unimportant information (such as a shirt pattern). After the signers were videotaped, the stimuli were processed off-line (not in real-time) one video frame at a time. Each frame was feature-extracted, and the results for each frame were stored in a disk file. By doing so, the stimuli could be animated at various frame rates by using only those frames needed for that rate (i.e., every frame for 30 fps; every third frame for 10 fps; etc.)

Stimuli

Stimuli consisted of 30 signs, 60 fingerspelled sequences, 6 sentences, and 6 questions. Three signers were used, each one producing one-third of the stimuli.

Signs. Thirty sign stimuli were selected for the trait of either robustness or fragility on the handshape dimension of a sign (Bornstein and Jordan, 1984), which may be the sign feature most vulnerable to distortion in the feature-extraction process. Half the signs were presented with lip movement and half without. The variables of robustness/fragility, presence/absence of lip movement, and signer were counterbalanced in the order of presentation of the signs.

Fingerspelling. For the fingerspelled stimuli, 30 words of four letters and 30 four-letter sequences were used. In the list of real words, an attempt was made to approximate the frequency of appearance of letters in English. Nonsense sequences were created by random selection of the same letters used in the real words. Three signers were used. Thirty stimuli were presented at 100 letters per minute and 30 were presented at 240 letters per minute. (For purposes of this study, we have designated these two rates as 'slow' and 'fast,' but in practice, 240 characters per second is moderate speed; fingerspelling would not likely be considered fast until it reaches about 360 characters per minute.) The variables of real/nonsense words, speed, and signer were counterbalanced in the order of presentation of the fingerspelling.

Sentences and Questions. Six sentences were presented. Subjects repeated the sentence to the experimenter, who rated these for accuracy. Following each sentence, a question (in the processed form) was asked about the system, and Subjects answered the question. These answers were either coded as correct or entered in their English gloss form.

Subjects

Deaf subjects were recruited from the student body and staff of Gallaudet University. The 120 subjects were fluent signers and had been using sign language for at least ten years. All were high school graduates and 42% had completed college. Ages of subjects ranged from 18 to 50, with a median of 26. Ninety-two percent reported their degree of hearing loss as severe or profound.

Subjects were randomly assigned to one of five conditions: (1) standard videotape (control), or processed signs at (2) 30 frames per second (fps), (3) 10 fps, (4) 7.5 fps, and (5) 6 fps. Subjects were randomly assigned an order of presentation of signs, fingerspelling, and sentences.

Experimental Procedures

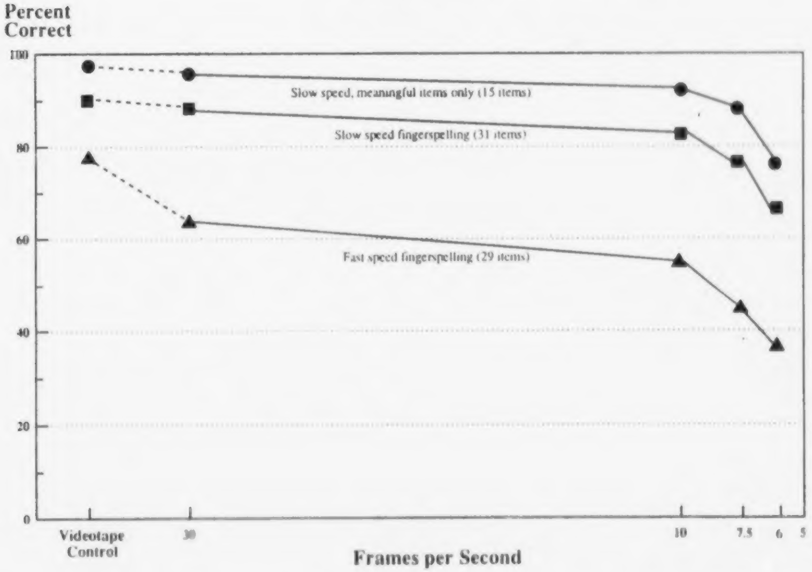
Subjects viewed a total of 16 practice sentences (eight sentences, each repeated once) in the experimental condition assigned to them, prior to viewing the stimuli; this was done to avoid training effects in presentation of the stimuli. Order effects were controlled by counterbalancing presentation of blocks of signs, fingerspelling, and sentences, and, within those blocks, by counterbalancing various features of the stimuli, as described above.

Table 1

Mean correct responses
(Relative Frequencies)

	Signs (30 items)	Fingerspelling (60 items)	Sentences (6 items)	Questions (6 items)
All conditions (n = 120)	94.64%	68.60%	71.67%	77.64%
Videotape Control (n = 24)	98.33%	85.35%	82.64%	95.14%
Processed				
30 fps (n = 24)	95.28%	75.42%	76.39%	80.55%
10 fps (n = 24)	94.72%	69.10%	72.92%	77.78%
7.5 fps (n = 24)	93.61%	61.11%	67.36%	72.22%
6 fps (n = 24)	91.25%	52.01%	59.03%	62.50%

Figure 1
Fingerspelling



Each subject viewed each stimulus and repeated (signed) what he or she saw. Guessing was encouraged and subjects were also encouraged to respond with real signs rather than approximations of signs. In the case of the questions, subjects answered the questions rather than repeating them. The experimenter then recorded either a code indicating correct response or the English gloss of the sign/fingerspelling/sentence, if the response was incorrect. All responses were videotaped. The videotapes were used for double-checking the responses against the data file.

RESULTS

Analysis of variance revealed no effect of presentation order of the blocks of stimuli (signs, fingerspelling, sentences/questions) on the number of correct responses [$F(5, 23) = 1.308$, $p = .193$]. The effect of frame rate, however, was statistically significant for all categories of stimuli [e.g., for signs, $F(4, 23) = 16.630$, $p < .001$; for fingerspelling, $F(4, 23) = 34.109$, $p < .001$)].

Mean percentages correct (see Table 1) indicate a degradation of intelligibility as fewer frames per second are presented. Intelligibility of stimuli was highest for individual signs and lowest for fingerspelling. Signs were more than 90% intelligible even at six frames per second.

Even in the control condition, fingerspelled stimuli proved to be less intelligible, perhaps because of the differing speeds and the inclusion of nonsense sequences. (It should be noted that the scoring of fingerspelling was rather strict; even if all letters were present in the response but the order was wrong, the response was scored as wrong.) However, meaningful words spelled at a slow speed (100 characters per minute) proved even more intelligible than signs (see Figure 1). Regardless of speed or meaningfulness, the fingerspelled sequences dropped off sharply in intelligibility at 7.5 frames per second. The difference in intelligibility between 30 frames per second and ten frames per second was small and probably insignificant for practical purposes.

Of interest are the differences between the videotape control condition and the processed condition at 30 fps, as these two conditions differ in spatial resolution but not in frame rate. For individual signs, the difference in intelligibility is quite small, roughly 3% on average. For answering questions, which depends on the ability to comprehend the content of two sentences (including the question), the difference between the control condition and the processed condition at 30 fps was nearly 15%. In the control condition, Subjects scored better on the questions than on the sentence-repetitions, presumably because of redundancy in the language (with questions providing clues to signs that were missed during the sentence-repetition.) In the processed condition, the improvement was not as great.

DISCUSSION AND CONCLUSIONS

The findings indicate that ten frames per second may be an optimum rate; more than ten frames per second yielded greatly diminished returns. Fewer than ten per second had a marked negative effect on intelligibility, for stimuli that were executed rapidly (near normal levels of speed). Of course, if one signs and fingerspells very slowly, these rates could be accommodated, but it is unlikely that ongoing "slow motion" signing would be acceptable to users.

The spatial resolution, considered alone, had the greatest negative effect on the intelligibility of fingerspelling at moderately fast speed, and on the questions.

Additional analyses will be done to determine the effects, if any, of intelligibility of signs with which lip movement was done; of individual signers; and of robustness or fragility of signs.

The next round of system development will involve improvements to the spatial resolution, if possible, and the development of a system operating in real-time.

The next round of experiments with users will involve observation of dyads using a real-time system. These studies will provide insight into the amount of accommodation users are willing to make to use such a system, the reaction of users to the aesthetics of the system, and the degree to which conversations can be sustained.

REFERENCES

Galuska, S. (1990). Parallel Methods of Feature Extraction for Low Bandwidth Transmission of Sign Language. Master's Thesis, University of Delaware.

Letellier, P., Nadler, M. and Abramatic, J. F. (1985). The Telesign Project. *Proceedings of the IEEE*, Vol. 73, No. 4, pp. 813-827.

Pearson, D. E. and Robinson, J. A. (1985). Visual Communication at Very Low Data Rates. *Proceedings of the IEEE*, Vol. 73, No. 4, 1985, pp. 795-812.

ACKNOWLEDGEMENTS

This work was supported by the Department of Education, National Institute for Disability and Rehabilitation Research through grant #H133G80170 to the University of Delaware. The authors also gratefully acknowledge the support of the Nemours Foundation and Gallaudet University.

Judith E. Harkins
Gallaudet University
800 Florida Avenue, NE
Washington, DC 20002

ASCII-based TDD Products:
Features and Compatibility

N. S. Williams, C. J. Jensema, Ph.D., and J. E. Harkins, Ph.D.
Technology Assessment Program
Gallaudet University

INTRODUCTION

Deaf people communicate by telephone primarily through the use of Telecommunication Devices for the Deaf (TDD). TDDs are the electronic generation of devices that evolved from old teletype machines (TTY) which transmit signals through the telephone network by means of acoustic couplers. These older TTYs and newer TDDs use Baudot, a five-level code that is incompatible with the standard code used by computers.

The limitations of Baudot as used in the TDD network include (1) operation in true half-duplex, making it impossible to interrupt the other party in a conversation; (2) incompatibility with ASCII, a feature which severely limits the number of terminals with which the TDD can communicate; and (3) slow speed (45.45 baud) which limits transmission to roughly 60 words per minute.

Beginning in the late 1970s, manufacturers began to introduce ASCII into TDDs. Since that time, many models of TDD have offered ASCII as an option. In the 1980s, companies began to introduce translation modems that allowed personal computers to perform as sophisticated TDDs on both Baudot and ASCII calls. With such products, a computer user can exploit the many features of the computer (e.g., large screen, color graphics, time and date stamps, capacity for large directories) while communicating with users of Baudot.

Today approximately a dozen TDD products offer ASCII. Still, few deaf people use ASCII for telephone conversation. The overwhelming majority of calls are still transacted in Baudot.

There are many valid reasons for this continued dedication to Baudot. The complexity of ASCII communication protocols is baffling to many computer users, whether hearing or deaf. In addition, the person receiving a call cannot hear the incoming signal and therefore has no way of knowing whether the caller is using ASCII or Baudot. Some devices detect the incoming code (which the deaf TDD user cannot hear) and automatically adjust the communication protocol to that of the calling device; but some do not offer auto-detect.

Still another problem is that many devices require the caller to know the communication protocol (such as number of bits, parity, and stop bits) used by the called party, and to set up for that protocol before placing the call. A hearing person may solve this problem by placing a voice call to the other user and discussing the communication protocols to be used, but for deaf people this is not an option.

Many modems are set to disconnect if there is an interruption in the carrier tone. This feature is inappropriate for using the computer as a TDD, because interruptions to the line are commonplace (a call is transferred, a hearing family member picks up the extension phone, etc.).

To understand the problems associated with ASCII use, one must first view the computer in this context as a simple telephone, not as a sophisticated data-sending machine. If the most routine requirements of telephone conversations are not met by the computer, then it will not be used by deaf people for that purpose.

Needed are a better understanding of the products available to deaf people, the callers' requirements, and, perhaps, standards for communication protocols used in these products.

The objectives of this study were to determine the compatibility among the various ASCII-TDD devices on the market, to compare features of these devices, and to recommend to manufacturers steps that might be taken to simplify ASCII-based TDD communication.

METHOD

The investigators acquired copies of 11 ASCII-based products offered by seven manufacturers. The devices included stand-alone TDDs with ASCII features (Ultratec Supercom and Superprint 400, Krown PV-20+ and MP-20A, and AT&T 1310 Plus); internal translation modems (Vieu-Tek MIC300I, IBM PhoneCommunicator); external translation modems (Krown SM-85, Phone TTY CM-4, and Ultratec Intelemodem); and a Hayes modem.

Two residential telephone lines were acquired for placing and receiving calls in the evaluation, to avoid the possible intervention of signalling protocols within the university's PBX. Calls were placed among all possible combinations of devices, with one exception: Calls were not made between two identical devices, because we did not have two copies of each device.

Where the direct-connect feature (connection through modular jack) was present, it was used for the call; acoustic couplers were used only in the absence of direct-connect. Calls were placed in ASCII, using the default protocol of the device. If the device required manual setting of ASCII (turning it on), then that was done. If the device had auto switching between Baudot and ASCII, then manual switching was not done unless the auto switching failed.

A call was considered successful if these conditions were met:

> The two devices connected *in ASCII*. (If both switched to Baudot, the call was counted as a failure for purposes of this study.)
>
> Both parties could see their own typing and the typing of the other party
>
> For devices with full screens, the linefeed/carriage return functioned adequately

In addition to the compatibility check, an inventory was taken of features relevant to ASCII communication for the ten devices that are specialty products for deaf people.

RESULTS

Compatibility check

One of the key points of interest of this study was the extent to which deaf people could successfully make calls to other TDD products, using ASCII, without having to reset parameters from the default setting.

Each device was used to call every device except itself, giving a total of 11 x 10 = 110 calls. Since the ability of a device to handle outgoing calls was considered separately, we effectively evaluated 110 outgoing call situations and 110 incoming call situations.

Of the 110 outgoing calls, 77 (70%) were unsuccessful *when both devices were in their respective default settings*. In other words, the calling party would experience either (1) automatic switching to Baudot, (2) failure to establish a connection or (3) problems such as garbling, linefeed/carriage return problems, or inability to see the caller's own typing--if the caller simply turned on the device and called (which of course is possible when all devices are using Baudot).

Of the 110 incoming calls, 81 (74%) were unsuccessful *when both devices were in their respective default settings*. In 74% of the calls, the receiving party would experience automatic switching to Baudot, failure to connect or some garbling or other transmission problem.

The calling party has no way of knowing whether the receiving party is having problems with transmission. When each call is considered as one unit, then the number of successful calls (as defined here) is much smaller: Only 13% of the 110 calls were successful on both ends, when both devices were in their respective default settings.

It is important to note that many of the "failed" calls were in fact functionally successful, in that Baudot was invoked and used during the call. This happened frequently when both devices had automatic set-up/detection for incoming and/or outgoing calls.

However, with devices that had only a manual switch for ASCII, the default settings were not very helpful. There were 14 possible calls from devices with only manual switching for outgoing calls to other devices with only manual switching for incoming calls. When the ASCII feature was turned on in the default protocol and the calls were placed, all 14 calls failed. Because there is no automatic switching, these failures do not include switches to Baudot.

BEST COPY AVAILABLE

TDD/ASCII FEATURES COMPARISON

	ULTRATEC SUPERCOM	KROWN PV-20+	AT&T 1310 PLUS	ULTRATEC SUPERPRINT 400	KROWN MP-20A	VISU-TEK MIC2000	IBM PHONE COMMUNICATOR	ULTRATEC INTELEMODEM	KROWN 300-88	PHONE-TTY CM-4
DEVICE TYPE	STAND ALONE	STAND ALONE	STAND ALONE	STAND ALONE	STAND ALONE	INTERNAL MODEM	INTERNAL MODEM	EXTERNAL MODEM	EXTERNAL MODEM	EXTERNAL MODEM
CONNECTION TYPE	ACOUSTIC & DIRECT	ACOUSTIC & DIRECT	DIRECT	ACOUSTIC & DIRECT	ACOUSTIC	DIRECT	DIRECT	DIRECT	DIRECT	DIRECT
SOFTWARE INCLUDED?	BUILT-IN	BUILT-IN	BUILT-IN	BUILT-IN	BUILT-IN	YES	YES	NO	NO	YES
TOUCH TONE DIALING	-	-	-	-	(2)	✓	✓	✓	✓	-
PULSE DIALING	✓	✓	✓	✓	(2)	✓	✓	✓	✓	✓
BUSY CALL DETECTION	-	-	✓	-	-	✓	✓	✓	-	-
INCOMING CALL: AUTO ASCII & BAUDOT DETECTION	✓	-	✓	✓	-	✓	✓	✓	AUTO ANSWER MODE ONLY	✓
OUTGOING CALL: AUTO ASCII & BAUDOT DETECTION	-	-	✓	-	-	✓	-	✓	-	-
EQUIPMENT NEEDED	NONE	NONE	NONE	NONE	NONE	ANY IBM PC WITH UNUSED 8 BIT SLOT	ANY IBM PC WITH UNUSED 8 BIT SLOT	SOFTWARE & ANY COMPUTER WITH UNUSED SERIAL PORT. (1)	SOFTWARE & ANY COMPUTER WITH UNUSED SERIAL PORT.	ANY IBM PC WITH UNUSED SERIAL PORT
COST (WITH ASCII)	$329.00	$350.00	$420.00	$538.95	$579.00	$275.00	$800.00	$289.00	$309.00	$349.00

NOTES: (1) = Requires special 9 pin male cable to the modem. (2) = This product came with acoustic cups only. No direct connection on this model.

✓ = Yes " = No ? = Product not yet available to evaluate.

TDD/ASCII PROTOCOLS COMPARISON

	ULTRATEC SUPERCOM	KROWN PV-20+	AT&T 1310 PLUS	ULTRATEC SUPERPRINT 400	KROWN MP-20A	VISU-TEK MIC2000	IBM PHONE COMMUNICATOR	ULTRATEC INTELEMODEM	KROWN 300-88	PHONE-TTY CM-4
DEVICE TYPE	STAND ALONE	STAND ALONE	STAND ALONE	STAND ALONE	STAND ALONE	INTERNAL MODEM	INTERNAL MODEM	EXTERNAL MODEM	EXTERNAL MODEM	EXTERNAL MODEM
8N1	-	-	-	-	-	✓	✓	✓	-	✓
7E1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
HALF DUPLEX	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
FULL DUPLEX	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
110 BAUD	✓	✓	✓	✓	✓	-	✓	✓	✓	✓
300 BAUD	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1200 BAUD	-	-	-	-	-	-	✓	-	-	-
RUNS STANDARD COMMUNICATION SOFTWARE	-	-	-	-	-	-	-	✓	✓	-
FILE TRANSFER (text & binary)	-	-	-	-	-	text only	text-in only	✓	text only	text only
RUNS PRODIGY	-	-	-	-	-	-	-	-	-	-
FACTORY DEFAULT SETTING FOR RECEIVING ASCII CALLS	300 BAUD 7E1 HALF DUPLEX	300 BAUD 7E1 FULL DUPLEX	110 BAUD 7E1 HALF DUPLEX	300 BAUD 7E2 HALF DUPLEX	300 BAUD 7E1 HALF DUPLEX	300 BAUD 7E1 FULL DUPLEX	300 BAUD: 7E1 1200 BAUD: 8N1 HALF DUPLEX (1)	SOFTWARE DEPENDENT	300 BAUD 7E1 HALF DUPLEX	300 BAUD 8N1 (2) HALF DUPLEX (1)

NOTE: (1) = Default is changeable (2) = 8th bit stripped ✓ = Yes " = No ? = Product not available to evaluate

There were 18 possible calls among devices with the automatic detection for outgoing calls and/or automatic detection for incoming calls. For these calls, the procedure was simply to leave the device in the auto condition. Results were: 3 successful connections in ASCII, 2 switches to Baudot, and 13 failures.

It is very important to note that *all devices were able to communicate in ASCII with all other devices once the parameters were re-set so as to be compatible*. This re-setting requires extensive knowledge of the other device and--for the seven devices that do not automatically switch between Baudot and ASCII on outgoing calls--also requires that the user be certain that the call will be answered in ASCII (rather than Baudot).

Features Inventory

Of the 11 devices in this study, 10 were designed specifically for use by deaf people. Figure 1 and Figure 2 present the features of the ten devices examined. Only three automatically switch between Baudot and ASCII on outgoing calls. Eight of the models examined had automatic switching for incoming calls. In order for two devices to successfully communicate in ASCII without user involvement, both must have automatic switching both for outgoing and incoming calls. In other words, devices that switch between Baudot and ASCII for incoming calls will end up communicating in Baudot unless the calling device has automatic switching for outgoing calls.

Of the ten products for deaf people, only four offered touch-tone dialing; the rest were either pulse dialing or no option (acoustic coupling only). Although this is usually no major inconvenience, sometimes pulse dialing can trigger flashing signal systems, which can confuse people other than the caller.

Only one device--the IBM PhoneCommunicator--offers 1200 baud at this time (although a number of manufacturers are promising 1200 and 2400 baud in the future). For telephone conversations, 300 baud is adequate, and even offers some advantages over higher speeds because it permits acoustic coupling without significant disturbance (acoustic coupling is the only available option when using pay phones, for example). But for contacting many bulletin board systems and other information networks, 1200 or higher baud is necessary.

The number of features offered and the technical nature of many of these features make it clear that purchasing such equipment is a difficult consumer decision. One result is that few deaf people even try. Anecdotal reports from manufacturers and distributors indicate that there is little demand for ASCII among deaf TDD users.

CONCLUSIONS AND FOLLOW-UP

The compatibility study revealed that, although all devices on the market could successfully connect after the user had properly adjusted the device away from the default setting, the default protocols used in these devices rarely allowed connection in ASCII with other types of devices on the first call. Thus, use of ASCII requires patience, an understanding of the implications of the various dimensions of the communications protocol, and willingness to tolerate failed calls.

Again, in evaluating these results, it is important to view computer modems and protocols in this context as telephones, not as data transmission devices. Hearing people do not tolerate failed calls easily; imagine the frustration of being able to complete only 13% of voice calls as desired because the telephone was not appropriately set up.

These problems need to be solved before deaf people will be willing to use ASCII for conversing. There are several possible partial solutions to these problems.

Standards for ASCII protocol as used in TDDs

One partial solution is to have all manufacturers agree to certain standards in communication protocol. The goal should be to allow deaf people to complete calls with as wide an array of devices as possible, without requiring knowledge of data communications and without the need to do manual switching. If one protocol can reach all ASCII TDDs as well as Hayes modems and bulletin board systems, then deaf people might venture into using ASCII more often and begin to realize its benefits.

To take a step in this direction, the manufacturers of these devices were asked by the researchers to meet and discuss the issue of compatibility and ease of use among the ASCII-based TDD products. Four of the six manufacturers whose products were evaluated attended a discussion meeting held during the convention of the National Association of the Deaf; the two remaining manufacturers subsequently expressed interest in attending future meetings. A second meeting will be held in June, 1991 during the convention of Telecommunications for the Deaf, Inc. It is our hope that, by suggesting a standard for TDD communication, we may, at modest cost to manufacturers, overcome some of the barriers associated with ASCII use and realize some of its benefits for communication.

Preliminary discussions indicate that manufacturers are considering Gallaudet's proposal that default settings in TDD/ASCII products would be half duplex, eight bits *with the eighth bit stripped*, no parity, one stop bit (8-N-1), which is the same as seven bits, space parity, one stop bit (7-S-1). This change may permit deaf users the needed flexibility to use their devices to call a variety of types of ASCII TDDs as well as bulletin board systems and Hayes modems.

Standards for "regular" computer modems

If Baudot were included in all computer modems, then standard modems could be used by deaf people, with software enabling the user easily to handshake with other devices including TDDs. If manufacturers begin to realize the potential market force for disability-related products as a result of the Americans with Disabilities Act, perhaps we will see some movement in this direction.

Gateway services that provide protocol conversion.

Another possibility would be to include the intelligence necessary for protocol conversion within the telephone network and offer it as part of dual-party relay service. The functional aspect of the system would work as follows: A deaf caller using either ASCII or Baudot, in any of the possible communication settings available in TDD products, would call a particular number (the gateway), where a computer would answer and establish communication. The computer would ask for the number to be called; the deaf person would give the number and the system would dial the number. The system would then successfully connect with the dialed number's terminal, whether it might communicate in ASCII or Baudot. Then the deaf person and the person being called could chat, using the gateway. A relay operator would not be necessary, meaning that privacy would be preserved and costs would be reduced. This type of arrangement would, for the first time, effectively link the millions of hearing computer users with the deaf community.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Education, National Institute on Disability and Rehabilitation Research, as part of the Rehabilitation Engineering Center on Technology for Deaf and Hard of Hearing People (H133E80019) based at the Lexington Center. The work was carried out at Gallaudet through subcontractual arrangement. The authors also gratefully acknowledge Dick Brandt of db Consulting, Annandale, New Jersey, for his advice, and the manufacturers of ASCII-TDD products for their cooperation.

BEST COPY AVAILABLE

4.3 EVALUATION OF LIQUID CRYSTAL DISPLAY PANELS FOR PRESENTING REAL-TIME SPEECH-TO-TEXT TO PERSONS WITH ACQUIRED DEAFNESS

Gunnar Fagerberg[1], Gerhard Elger, Lars Bäcklund, MD[2], and Barbro Furugren
The Swedish Handicap Institute, Stockholm, Sweden
[1]and INROADS, London, Ontario, Canada
[2]St. Erik Eye Hospital, Stockholm, Sweden

ABSTRACT

A system for transcribing Swedish text at the rate of normal speech to persons with acquired deafness has been developed. One part of the project was an evaluation of liquid crystal display panels for presentation of the text. 16 different products were tested. Several of them provided an acceptable projection if the overhead projector, the screen and the room illumination permitted.

BACKGROUND

The problem of providing real-time transcriptions of speech in meetings, conventions, etc to persons with acquired (total) deafness has been addressed in several countries by the use of chord keyboard systems and specially trained operators (5,6). In Anglo-Saxon countries, traditional phonetic keyboards, originally used in court reporting, have been employed for this purpose.

After a study of existing systems, it was decided to use the Dutch keyboard Velotype, which is orthographically based. A version for the Swedish language was developed and operators were trained. Transcription services at the rate of speech are now provided as part of the assistive devices service delivery system in Sweden. The project has been reported in Swedish (3). For a report in English with detailed descriptions of different chord keyboards and the reasons for the choice of Velotype, see (2).

One question remained: which is the best way to present the text in different situations? Computer monitors give an acceptable picture but can only be used with small groups of readers. One low-cost 3-color LCD projector was tested with fair results but was not judged cost-effective for display of text. Video projectors for home use give too low quality in relation to their cost. Professional video projectors are available for projecting computer graphics with very good quality at a very high cost. A better option seemed to be computer liquid crystal display (LCD) panels, used with overhead projectors, as recommended in (4).

However, more information on existing products and the quality of their output was needed. Thus, a study and evaluation of different computer LCD panels was carried out. It has previously been reported in Swedish (1).

LCD panels, also known as computer projectors, data displays, flat screen overheads, electronic imaging systems, etc., are flat, transparent screens containing liquid crystal cells. They are designed to be placed on an overhead projector to display the output from a computer on a screen to a large audience.

The type of graphics standard used in the computer determines the possible choice of LCD panel. Some panels need special accessories (cables) to handle several graphics standards.

EVALUATION

At the end of 1989, about 30 panels were available on the Swedish market. Some were the same model under different brand names. Sixteen different products were selected for evaluation. For the final evaluation, three overhead projectors of different quality and different types of projection screens in varied light conditions were used.

The computer used was a Victor V286A with IBM original CGA, Victor Hercules compatible, EGA compatible and VGA compatible graphics cards, one card at a time being used in the computer.

The software used was Microsoft Windows and the specially created program included a black screen, a white screen, a white rectangle with a black frame and patterns for contrast evaluation. Using Windows Write and Helvetica font, text demonstration screens with small and large text size were used. With the largest size the screen held nine lines of text. Grey scale and color scale were also evaluated.

The light reflected from the screen was measured at the center and the corner.

Text and graphics displayed were judged by human subjects.

Special requirements of the text-to-speech application were considered: text display is more important than graphs and continuous use for several hours is required.

RESULTS

The overall result was that the best combinations of LCD panel and overhead projector, such as the Elmo monochrome LCD panel used with Elmo or Liesegang overhead projectors, gave a very good text display.

However, the characteristics of the overhead projector are crucial. It is difficult to obtain sufficient light flow: the LCD panel absorbs at least 50% of the projector light. The projector lamp must be at least 250 W. 400 W is preferred, if cooling is efficient. The projector should not heat the display to more than 45°C. The optics should have three or four lenses, of good quality.

The projection screen and the room illumination are also important for obtaining maximal contrast. It must be possible to tilt the screen so the distances from the projector to all four corners of the screen are equal. No light from the room illumination should fall on the screen, or the contrast will be reduced considerably. The reflection properties of the screen should be chosen according to the width of the viewer area, not too wide, not too narrow.

Computer projectors capable of handling many different graphics standards proved to produce a lower display quality. VGA compatible displays absorbed more light than did the black-and-white Elmo EGA display or the blue/white Norwegiean ASK Hercules display, often necessitating the use of high-quality 400W overhead projectors.

Of the tested VGA compatible displays, In Focus Systems (PC Viewer) 480 GS showed good results.

Among the EGA compatible displays, Kodak Datashow HR was easy to handle and gave a good picture, although it was not quite as transparent as some others.

False-color displays were judged inferior for the display of text, due to greater light absorbtion and lower contrast.

Some of the evaluated products had a remote control. It was not considered to be a necessary accessory for the display of text only.

ACKNOWLEDGEMENTS

This project was supported by the Swedish Ministry of Health and Social Affairs. The Dopping report (2) was also supported by Swedish Telecom.

REFERENCES

1. Bäcklund, L.: *Att visa skrivtolkad text*. The Swedish Handicap Institute,Stockholm, Report no. 90207, 1990.

2. Dopping, O.: *The Chord Keyboard Report - Writing Clear Text with the Speed of Speech*. The Swedish Handicap Institute, Stockholm, Report no. 8204, 1988.

3. Furugren, B.: *Simultan skrivtolkning för vuxendöva hörselskadade*. The Swedish Handicap Institute, Stockholm, Report no. 90206, 1990.

4. Harkins, J. and Virvan, B.: *Computer-Assisted Notetaking for Hard of Hearing People*. RESNA '90, Proceedings of the 13th Annual Conference, Washington, D.C., pp. 363-364, 1990.

5. Steele, R.D.: *Stenotyped input in rehabilitation applications*. Proceedings of the 6th Annual Conference on Rehabilitation Engineering (RESNA), San Diego, pp. 168-170, 1983

6. Steele, R.D.: *Text output improvement in speech captioner performance*. Proceedings of the 2nd International Conference on Rehabilitation Engineering (RESNA), Ottawa, pp. 289-90, 1984.

Gunnar Fagerberg
INROADS
Thames Valley Children's Centre
779 Base Line Road East
London, Ontario
CANADA
N6C 5Y6

4.4 THE IMPORTANCE OF USER INTERFACE AND INTERACTION DESIGN

Linda W.Y. Chan
Royal College of Art
Department of Computer Related Design
Kensington Gore, London, United Kingdom

Abstract

With the current advances in modern technology, more and more assistive devices are being produced. Many are of complex mechanical and software design. Yet, it is important that they are user-friendly and require minimum effort from the user to obtain the maximum performance from the device. At the Department of Computer Related Design, we concentrate on the design of user interfaces and human machine interaction which is the dominant factor for usability. This paper decribes the design process of the user interface and interaction for a wrist-worn alerting device for deaf people.

Background

(Project Brief)
Select a person with a task or a problem that could be helped or solved by the use of a small hand-held computerised device. It is important that a real person is involved rather than an imaginary one, so he/she can provide a task or a problem and try out the solution when it has been designed.

Statement of the Problem

C.M. is a 41-year-old female who was deafened at an early age. She lives alone in a house and is employed by the Department of Education and Science as a middle manager. With the remaining 5-10% of hearing in one ear, her lipreading is assisted by a powerful hearing aid.
However, her flashing light system which is connected to the telephone (Qwerty) and the doorbell only works when the lights are turned on; this creates a problem as C.M. often forgets to turn her lights on especially during the day.
At work, C.M. shares an office with a colleague and they both have their own telephones. She can hear the ringing of the telephones, but cannot distinguish between the two. So, before she gets a flashing visual indicator for her telephone at work, this is what she has to do when she hears a telephone ringing and her colleague is not in the office: First, she picks up her telephone to see whether there is any response on the screen, if not she will have to scramble round to try to answer the other telephone. C.M. suggests that she would like to have a device which she could carry around with her and gives her a signal when the telephone rings or when someone is ringing the doorbell.

Approach

A review of existing devices was conducted in line with C.M.'s suggestion.
The major systems surveyed employ different patterns of either vibrations or flashing lights to alert the user of signals received from different sources, such as a doorbell, telephone, smoke detector, security alarm, etc. The non-portable mains systems use household lighting appliances to deliver the signals whereas the portable ones have belt-worn or wrist-worn vibrating receivers which can be worn on a belt or put into the user's pocket.
The main disadvantages of these systems are that they rely on the user's memory to differentiate the patterns of signals from the various sound sensors. The belt-worn receiver of the Silent Call system has a clearer visual interface with a series of LEDs on the receiver box, enhanced by printed icons and text. However, a belt-worn receiver may not be as convenient as a wrist-worn one and this particular system is limited to four different sensors : sound, telephone, doorbell and smoke detector.
The design solution to this particular problem is to have a conventional looking wrist watch with an LCD face. This would allow the system to be portable, flexible, compact and stylish.

Solution and Implications

When a sound based signal is received, the watch will vibrate to alert the user. The interface of this device is designed to provide a clear indication of the subject and direction of the sound source by using simple icons generated on the LCD. The use of an LCD means that the number of icons is only limited by the available memory of the processor.

The standard icons

The following figures show examples of alerting icons which flash when operating. The position of the user is represented by the centre of the watch face and the 12 o' clock position indicates the forward direction of the user.

Discussion

This device provides a pictorial user interface which transcends language barriers and requires no training. It therefore requires the minimum of thought to interpret a signal.

The design of an interface should always take into account the ability and needs of the user; and the interaction should be designed from the user's perspective.

Further work

This will involve prototyping the device described in this paper and developing a computerised braille learning tool for children with visual disabilities. This project will concentrate more on the human machine interaction aspect.

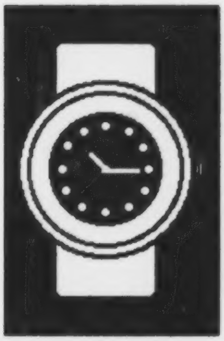


Fig.1 - Normal watch

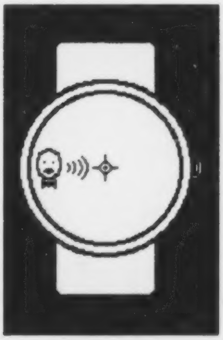


Fig.2 - A man's voice from the left

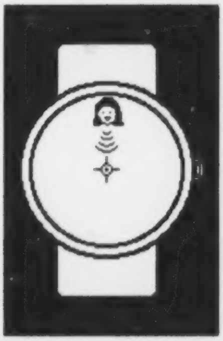


Fig.3 - A woman's voice from the front

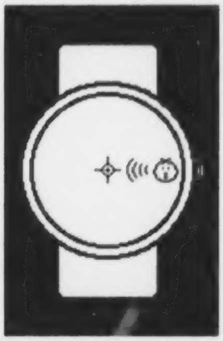


Fig.4 - A child's voice from the right

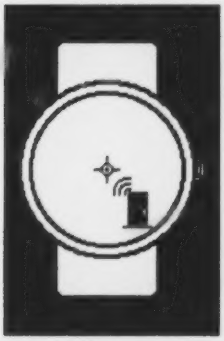


Fig.5 - A doorbell from the back right

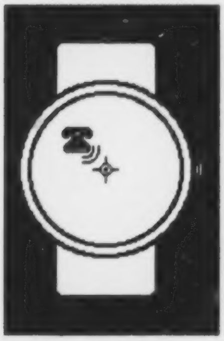


Fig.6 - A telephone from the front left

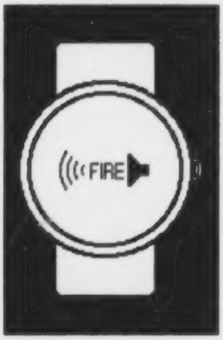


Fig.7 - The smoke detector or the FIRE ALARM!

Address:

Linda W.Y. Chan
Royal College of Art
Computer Related Design
Kensington Gore
London SW7 2EU
United Kingdom.
Email:Farca01@uk.ac.ulcc.mvs

5.1

VOICE AND HEAD POINTER OPERATED ELECTRONICS COMPUTER ASSISTED DESIGN WORKSTATIONS FOR INDIVIDUALS WITH SEVERE UPPER EXTREMITY IMPAIRMENTS

Jeff K. Burnett, Charles R. Klabunde, Catherine W. Britell
Washington State University, The Boeing Company,
and Seattle VA Medical Center

ABSTRACT

Individuals with severe limitations of upper extremity function have historically been denied access to the design disciplines. A consortium of individuals from corporate, government, and academic institutions has successfully developed a voice and head-pointer controlled keyboard and mouse control system to allow full and effective control over the CAD (computer assisted design) environment, using verbal commands plus controlled head pointing. This system is being successfully applied in the vocational training environment and the job setting for electronics computer assisted design.

INTRODUCTION

The area of electronics computer assisted design (ECAD) is an active and growing field for both technical and professional workers. A successful vocational and pre-professional program in ECAD has been developed at the Resource Center for the Handicapped, a vocational training institution for individuals with disabilities. The challenge of opening this program to individuals with severe upper extremity impairments has been addressed by a consortium of engineers, educators, and clinicians from private and public sectors, with resultant development of a voice and head-pointer operated system which affords efficient and effective interfacing to the hardware and control of the software applications necessary to successfully function in this area.

SYSTEM DESCRIPTION

The ECAD training program is centered on an industry standard UNIX based graphics workstation, which supports multiple simultaneous processes, high speed, high resolution graphics, along with networking. The workstations used are connected to an Apollo DS3550 file server via a high speed network. Software tools include: schematic capture, documentation, simulation, timing analysis, logic synthesis, PLD syntheses, picture editor, table generation, analog and digital circuit simulation, and libraries. Physical model software tools include: 3D design, surface generation, thermal analysis, BCB and IC layout. For the user with severe upper extremity impairment, the UNIX ECAD environment is accessed via a standard graphical user interface (GUI), from a Microsoft Windows 3.0 based IBM or work-alike computer through the X-Windows GUI standard link. The UNIX-based CAD host computer does not sense that the user's workstation is different from any standard X-Windows terminal, yet all input may be made by voice and head pointing on a DOS PC.

The speech recognition keyboard recognizes each word or utterance as a keystroke or series of keystrokes based on an edited vocabulary. Speech recognition hardware may be chosen on the basis of need for active vocabulary size and ease of training. In the ECAD context used here (electronics computer aided design command syntax), only small vocabularies are required, along with concatenated word utterances used to speed numeric input; therefore a simple and inexpensive voice module was chosen.

Telephone use and message recording and playback capabilities are part of the system. These permit the user to be interrupted by a telephone call while doing a speech-controlled task. With two words, the user may answer the phone, while the application remains frozen, and the speech recognizer listens only for the "hang up" work and its confirmation. Once the phone call is terminated, the user automatically resumes the application with the recognizer listening for the application vocabulary. An outgoing telephone or intercom call can be made using a phone manager software package, which has a "rolodex" of pre-stored numbers and names. A call may be directed by verbal name or number. When the user is away from the workstation, the PC and phone manager software may function as a telephone answering machine.

Controlling a keyboard verbally is only one part of efficient operation of a CAD workstation. Pointing and picking is another Most physically able CAD operators use a mouse, tablet, trackball, joystick or other pointing device. These workstations employ an active (wired) or passive optical target (for wireless, attendant free) head pointing device. The equivalent to mouse buttons may be verbal (for either the wired or passive target) or "sip and puff" (for wired only).

CONCLUSION

This system allows a person with little or no upper extremity function to be highly productive in a state-of-the-art technical or professional design environment, without compromise of capability or power by the user's special input needs. The result is that the user with a severe disability will be capable of competitive quality and quantity of work in a field where demand for qualified workers is high and compensation is excellent.

Support:
U.S. Department of Education
Grant # H128A01001
The Boeing Company
Mentor Graphics
Microsoft
Digital Equipment Corporation
Hewlett Packard
U.S. Department of Veterans Affairs
Resource Center for the Handicapped

Contact:
Jeff Burnett
School of Architecture
Washington State University
Pullman, WA 99164-2220
(509) 335-1937

5.2 EMG ACTIVATED SWITCH FOR CONTROL OF COMPUTER FUNCTIONS BY PERSONS WITH QUADRIPLEGIA

David K. Evans and Andrew Schoenberg
Physical Medicine and Rehabilitation Division
University of Utah Medical Center
Salt Lake City, UT

ABSTRACT

A switch activated by electromyographic (EMG) signals was developed to allow a person with C-2 to C-3 quadriplegia to control drawing and writing functions of a computer. The device is equipped with a light-emitting diode bar-graph which provides a visual feedback of the level of a processed EMG signal. The same bar-graph is used to adjust the threshold setting for activating the relay switch. The switch is used in conjunction with a mouth-controlled joystick. The EMG is recorded with three surface electrodes that are mounted into the head band of a baseball cap or a flexible foam pad that can be attached to any muscle showing detectable EMG activity. A $17 integrated-circuit differential preamplifier, built into the electrode pad, minimizes noise. This system is being used successfully by a quadriplegic engineer for computer aided design.

BACKGROUND

Persons with high level spinal cord injury (C-2, C-3) often have very limited head movement. They generally have to rely on a sip-and-puff switch with some type of scanning system for wheelchair, environment and computer control.

Scanning systems for computer access are limiting the use of many programs used in the work environment. Computer aided design (CAD), desk-top publishing, and various professional tools for management and preparation of presentations, increasingly require the use of a "mouse" or a device for controlling the cursor on the computer screen. The user-friendly approach of "point, drag and click", made popular by the Apple Macintosh© computer, is rapidly spreading to the IBM compatible computer world. Hence, making the "mouse" functions available to persons with only slight head movement can significantly increase their ability to use computers for a full range of functions.

STATEMENT OF THE PROBLEM

The problem addressed in this paper concerns those quadriplegics that have no perceptible hand or arm movement, and have very limited head movement. If the person can hold up his/her head and rotate it approximately 30 degrees in the side-to-side and up-down directions, ultrasonic [2] and optical head movement sensors are available (Prentke-Romich™ and Pointer Systems™). These systems come with a sip-and-puff switch and software to allow text entry and application independent cursor control. These solutions are appropriate where the head movement is sufficient and funding in the range of $1000 is available. Where head movement is restricted to less than about 15 degrees, or only tongue movement is available, a joy stick may be a functional alternative. Joysticks for game ports or with adaptors to the mouse port are commercially available at a relatively low cost ($50- $100). These systems require the ability to simultaneously operate a joystick and switch. This requires (1) the ability to activate a switch rapidly once or twice while maintaining a constant position of the joystick and (2) the ability to hold the switch on while moving the joystick. This last operation, called "click and drag", is also required for selecting many of the program's control functions which are activated by pull-down menus.

RATIONALE

Our initial approach to the switch problem was to use a mechanical eye brow switch, or a piezoelectric sensor to sense slight eyebrow movement. These proved to be unreliable. The position of the switch would have to be adjusted frequently by another person. The "click and drag" function in particular was difficult for our subjects. A tube for a sip- and-puff switch mounted on the joystick was also unsatisfactory. We, therefore, looked into the possibility of detecting the muscle activity by sensing the EMG (ElectroMyoGram) and using the level of this signal to close a relay. This paper describes the development and testing of such an EMG switch.

The ability to move the cursor on the screen and close a switch at a selected position also provides a means for text entry for those unable to access a mechanical keyboard. The equivalent of keyboard operation can be achieved by keyboard displayed on the computer's screen. By pointing to a letter on the screen using the "mouse", the user can then emulate the keyboard function by activating the " mouse" switch.

A public domain program for emulating the keyboard on an Apple Macintosh© has been reported previously [1]. Several similar programs are now commercially available (McIntyre Co. Michigan - Word Writer™; Prentke Romich - Head Master™, Ohio; and Pointer Systems - Freewheel Head Pointer™, Burlington VT).

DESIGN

The complete system for computer access is shown in figure 1. It incorporates the EMG switch device, a miniaturized joystick mounted on a rigid tripod, and a commercially available interface which adapts the potentiometer resistance changes of the joystick to the standard mouse port of the Macintosh© computer (Mirage ADB™ interface CH products, CA).

The part of the EMG switch connected to the operator, consists of three electrodes mounted in the head band of a baseball cap or mounted in a flexible foam pad for attachment to another part of the body that has detectable EMG signals. Since the EMG voltages are typically very small (100 to 500 μV) high gain with

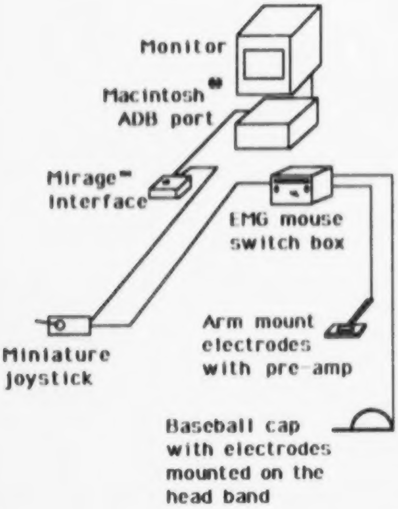

Monitor
Macintosh® ADB port
Mirage™ Interface
EMG mouse switch box
Miniature joystick
Arm mount electrodes with pre-amp
Baseball cap with electrodes mounted on the head band

Figure 1. Computer system showing elements needed for EMG switch and joystick operation.

minimal noise pickup is required. This was achieved by mounting an integrated-circuit, differential preamplifier (Analog Devices™ AD624) directly on the electrode assembly. The $17 dual in-line package requires no external components and is simply jumpered for a gain of 200. A flexible four-strand cable connects the electrode assembly to the EMG switch box.

EMG Switch Box

The circuit design of the EMG switch box is shown in figure 2. The preamplified EMG signal enters the first stage of amplification which has an externally adjustable gain. The next stage is a single-sided operational amplifier and filter. This stage half-wave rectifies the EMG signal and band-passes signals from 20 Hz to 200 Hz. This filtering eliminates D.C. components and high frequency noise. The next stage integrates the rectified but highly fluctuating signal, producing an almost constant voltage level proportional to the EMG amplitude. This voltage is compared to a constant reference voltage. The reference voltage is externally adjustable. When the processed EMG signal exceeds the reference value, the relay switch is closed, activating the "mouse" button.

EMG display

An important design feature of the EMG switch box is a visual display of the processed EMG signal level. This display is implemented as a 10 element light-emitting diode bar graph. This display is also used in setting the reference voltage for the comparator.

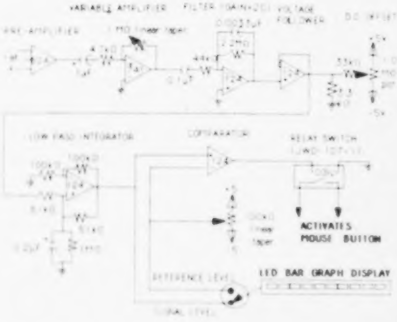

VARIABLE AMPLIFIER
FILTER (GAIN=20)
VOLTAGE FOLLOWER
DC OFFSET
PRE-AMPLIFIER
1 MΩ linear taper
2.2MΩ
+5v
-5v
LOW PASS INTEGRATOR
COMPARATOR
RELAY SWITCH
100kΩ
ACTIVATES MOUSE BUTTON
100kΩ linear taper
REFERENCE LEVEL
SIGNAL LEVEL
LED BAR GRAPH DISPLAY

Figure 2. Circuit diagram of EMG switch box showing amplification and filtering stages with the comparator for switch activation.

DEVELOPMENT

The design was implemented by the first author for his senior electrical engineering project over a 1 year period. The design evolved over several iterations. The first version used the computers power supply and had the differential preamplifier located in the switch box. The present version uses an AC adaptor which supplies12 volts and the differential preamplifier is mounted on the electrode assembly attached to the user. This eliminated most of the noise problems encountered in the early versions. Initially, pregelled pediatric ECG electrodes were used for interfacing to the skin. The most convenient and reliable signals were obtained by conductive adhesives interfaced to conventional clothing snaps.

The present version of the EMG switch uses readily available electronic components whose cost does not exceed $90.The labor costs are higher at this stage since the circuit is hand wired. A printed circuit version is being considered.

EVALUATION BY QUADRIPLEGIC

The system is being evaluated by a electrical engineer with a C3 injury. He uses a sip-and-puff switch with scanning control for wheelchair mobility. Computer access at home is provided by a voice activated system. He uses this primarily for programming, but has found that system not suitable for significant design or graphics. During the Initial evaluation in our laboratory a detectable EMG signal was obtained from his biceps. Figure 3a shows this signal amplified 200 times. Note that there appears to be only one large muscle unit firing at a rate of 30 Hz. Figure 3b is the resulting processed EMG signal used to activate the switch. The muscle unit contraction was visible under the skin but no movement of the limb was detected. The EMG from the eyebrow could also be used, but the user preferred the biceps position. Finding the proper position of the mounted electrodes to obtain reliable switch function requires some searching. The processed EMG amplitude display

(LED)on the switch box was used to locate the best position for the electrodes. The conductive adhesive electrodes are well suited for this situation where repositioning is required. Once properly positioned, the electrodes are stabilized by using a Velcro© strap. The gain of the amplifier is adjusted to provide full amplitude output on the LED display at a comfortable contraction effort. The switching reference voltage is adjusted by displaying it on the same LED display and setting this level at approximately 1/3 of full scale. The 1 inch long joystick is mounted in a small box to avoid obstructing the view of the computer screen. It is rigidly attached to a tripod positioned at mouth level.

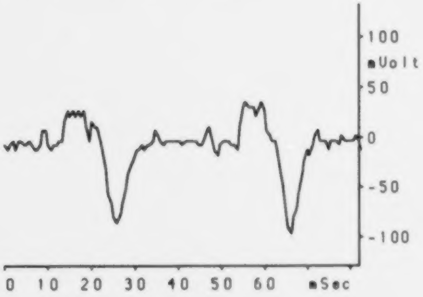


Figure 3a. Preamplified EMG from non-functional biceps muscle of quadriplegic showing one large motor unit.

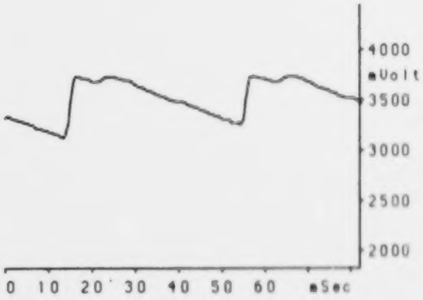


Figure 3b. Integrated EMG level after processing of EMG above.

It has required several hours of practice for the user to become proficient at positioning the cursor on the screen at the desired locations and activating the relay switch at the appropriate time. This is as expected, since efficient operation of the hand-held mouse also requires several days of practice for most normal users. The mounted electrodes and EMG switch are now functioning without need of adjustment for complete training sessions which last up to 3 hours. At this stage the test subject is training himself to use a CAD program to perform design functions. His goal is to become proficient at laying out printed circuit boards and designing electronic circuits using computer tools. Text entry is performed by using the Word Writer™ program which displays the keyboard on the screen. This program also displays up to 12 predicted words based on the first few letters selected. By pointing to the desired word and activating the EMG switch the entire word is entered into the active program automatically.

DISCUSSION

An EMG activated switch has been developed which has operated reliably for several months. It is a useful device for persons who have little or no anatomical sites for mechanical switch activation but do exhibit some residual volitionally controlled EMG activity in a muscle of a limb, shoulder or head. The bar graph display of the processed EMG level is an important feature of the device. It provides visual feedback for proper positioning of the electrodes, adjustment of the gain of the device, and setting an appropriate switch threshold level.

There are several limitations of this device. The disabled user is not fully independent when using this system. An attendant or other dexterous person must be present to attach and disconnect the electrodes and the EMG switch. This attendant must be trained for proper placement and adjustment of the device. The device is currently not battery operated. It is operated by an AC low-voltage adapter which generates 12 volts. No special effort was made to minimize power consumption. At this point the device is hand wired so that duplication involves considerable labor.

Greater precision in cursor control would also be desirable. We are evaluating the possibility of using a trackball mounted near the chin or mouth as the cursor control device. This device incorporates a second latching switch to eliminate the need for holding down the switch for operations requiring "dragging" or pulling down of menus. For this type of device a second EMG switch may be desirable.

REFERENCES

1. Schoenberg A.A. and J. Halleck (1987): Software for Screen Display of Keyboard for No-Hands Typing Via Ultrasonically Sensed Head Movements. Proc. 10th Ann. Conf. on Rehab. Technology. p. 685-7. RESNA, Washington D.C.

2. Robinson J. (1989): Computer Drafting for the Disabled. Proc.12th Ann. Conf. Technology for the Next Decade . p. 311-312. RESNA, Washington D.C.

David K. Evans
Physical Medicine and Rehabilitation Div.
University of Utah Medical Center
Salt Lake City, Utah 84132

A Programmable Scanning Keyboard for the IBM PC

P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hung Hom, Hong Kong

ABSTRACT

A hardware 8x16 programmable scanning keyboard was designed for IBM-PC-compatibles to avoid the incompatibility problem of a memory-resident software keyboard with graphics-based programs such as those for Chinese word-processing. Each position can be programmed to output up to 4 keystrokes each. Two layouts are built-in. One layout is optimized for English word-processing and the other for Chinese word-processing. Other layouts can be composed with ease using the supplied Layout Editor and downloaded to the keyboard. It supports single-, dual- and 5- switch input. Layout data and operating parameters are stored in memory with battery back-up.

BACKGROUND

For the disabled who cannot operate a standard keyboard, a software or hardware alternative keyboard may be used as an input device. Operation of the scanning keyboard is through an appropriate ability switch chosen for the particular disabled person using it.

STATEMENT OF THE PROBLEM

Software keyboards are memory-resident software packages that work well with a wide range of software. However, in the case of IBM-PC-compatibles, some graphics-based software such as those for Chinese word-processing, software incompatibility is a problem. IBM-PC-compatibles are ubiquitous in this city.

Hardware scanning keyboards should have no software incompatibility problem. The major flaw, besides the high cost, is that they usually have a fixed layout optimized for English word-processing. Since both English and Chinese based software are widely used locally, a hardware scanning keyboard which can cater to at least two languages is needed for the disabled user.

RATIONALE

Input efficiency is slow using a scanning keyboard. Efficiency can be improved using statistical layouts for an alphabet-based language, such as English. Chinese characters are non-alphabetic. There are several popular methods of inputting Chinese characters and they require different layouts to optimize input efficiency.

It is interesting to note that while the more sophisticated software keyboards developed in North America use word-predication to increase input efficiency, all Chinese operating systems have word-predication built-in because of the imprecise nature of several popular input methods.

While it is not possible to implement word-predication in a purely hardware alternative keyboard, it is possible to increase efficiency if each position can be programmed to output more than one keystroke.

Based on the above reasoning, a scanning keyboard appropriate for use in this city should have the following characteristics: -

1. Works on IBM-PC-compatibles
2. Statistical layout for English word-processing
3. Layout optimized for the most popular method of Chinese character input.
4. Programmable layouts to suit individual preferences.
5. Each position should be able to output more than one keystroke to increase input efficiency.

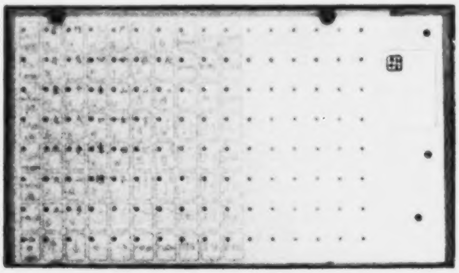


Fig. 1 Front panel with overlay for Chinese input

DESIGN

Programmable scanning keyboard (Fig. 1)

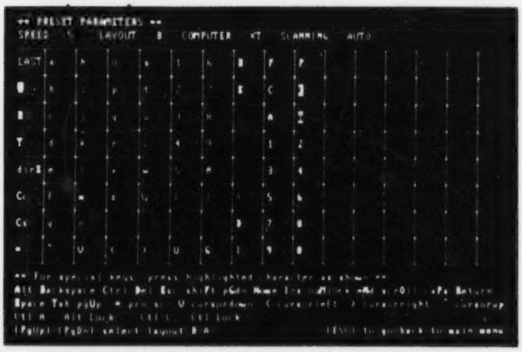
The heart of the keyboard is a Motorola MC68705R3 single-chip micro-computer. Layout data and operating parameters are stored in memory with battery back-up. An on-board interface allows downloading of layouts from a PC via a printer port. The standard keyboard and the scanning keyboard plug into a small junction box which in turn plugs into a PC keyboard input socket. This junction box serves as a simple automatic electronic switch to allow use of the scanning keyboard with the standard keyboard without conflict.

The matrix size of the keyboard is 8x16. Two pre-programmed 8x10 layouts are provided. One layout has the alphabets arranged in the usual statistical English order. The other layout has the alphabets arranged according to the most popular Chinese character input method. Three transparent overlays are provided---two for the pre-programmed layouts and an unfilled one for a custom layout.

Enough memory is provided to enable each position to output up to four keystrokes each. Since only 8x10 positions are required to implement the most frequently used keys of standard keyboards, the large matrix size leaves room for a small 'command/phrase library' or special tables for various Chinese input methods.

The keyboard will not scan consecutive blank rows or columns so as not to decrease input efficiency. One interest consequence of this feature is that the scanning matrix size is programmable.

To accommodate for a wide range of users, the keyboard supports single-, dual- and 5-switch input. Access is most efficiency with a 5-switch joystick. The first column contains user selectable operating parameters. These parameters include choice of eight scanning speeds, two layouts, XT or AT keyboard compatibility, auto- or manual- scanning mode, and type of switch input.



```
** PRESET PARAMETERS **
SPEED  5    LAYOUT  B   COMPUTER  XT   SCANNING  AUTO
** For special keys, press highlighted character as shown **
(PgUp) (PgDn) select layout B A              (ESC) to go back to main menu
```

Fig. 2 Layout Editor with the pre-programmed layout for Chinese input

Layout Editor (Fig. 2)

The Layout Editor allows the user to customize the keyboard for his own needs. Layouts stored on disk can be retrieved for modification or downloading to the scanning keyboard. A layout contains the keystrokes to be outputted by each scan position as well as operating parameters such as choice of scanning speed and layout ID.

The editor is user friendly with simple menu selections, an on-screen matrix resembling that of the physical scanning keyboard and on-screen instructions.

EVALUATION

Fifteen keyboards were sold to the local educational authority. Some of these have been in use in special schools. Evaluation results will be known in the near future.

One keyboard has been used by an adult quadriplegic for several months. This user does extensive Chinese word-processing and finds the programmable feature most useful in implementing his favourite character input method.

DISCUSSION

This hardware scanning keyboard aims to provide an appropriate solution to solve a local need. Measures taken to achieve this are built-in flexibility and facilities to increase input efficiency.

One interesting use of a programmable matrix size is that the keyboard can be used as an answer pad with only a few choices. This can be achieved by either limiting the matrix size to a few scan positions or making blocks of scan positions to output the same keystroke.

The hardware approach is inherently more expensive than the software approach because of the high hardware cost. It is only necessary because of software incompatibility. This problem can only be solved with standards arrived at by software producers. With the increasing popularity of 'windows' compatible software, the problem should diminish accordingly.

ACKNOWLEDGMENTS

The technical expertise of S.C. Siu is greatly appreciated. This work was supported by the Royal Hong Kong Jockey club.

P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic
Hung Hom
Hong Kong

A model for designing an alternative access system for the Macintosh™

Kim Adams, B.Sc. EE,
Madenta Communications inc. (Edmonton, Canada)
Shawn Abbott, B.Sc.
the AND group inc. (Calgary, Canada)

Abstract

An ideal human-computer interaction (HCI) system for physically limited users must accommodate radically different access methods. We have created a system for authoring alternative HCI which allows customization of the input method and of choices presented to the user by the computer. An important implication of this system is that more control and speed can be given to the user since a more direct method of computer access is used. This paper discusses the capabilities deemed necessary for such a system, the system structure, and alternative interfaces which could be created with it.

Background

From the user's point of view there are two components to HCI: the physical input device and the information the computer gives to and receives from the user. This information is conveyed by a graphic interface (GI) from which the user is to pick choices such as letters, word predictions or macro functions. When determining the best input method and GI for a computer access system, several issues must be considered (2,3):

- Physical capabilities. Every person will be best suited to a unique combination of input devices. Allowing the computer to maximize the information obtainable from this combination is the most important factor determining user access speed and sense of control. One way to do this is to use different alternative access devices concurrently, for example, a headpointer to select letters from a graphical keyboard layout and an extra switch to activate a modifier key such as shift. Variables like visual acuity and movement accuracy affect how the graphical keyboard should be arranged and sized (2).

- Application. Information conveyed to the user by the graphical interface should depend on the functions required by the software the user is running. For example, we have included the ability for the interface to provide adaptive word prediction based on past input. This option would be advantageous for word processors and voice generation but not in a graphics package.

- Computer hardware. Our development is implemented on the Macintosh computer which comes in several models, so any alternative input system needs to be able to be tailored with these differences in mind. The size of the computer screen is one example of a hardware consideration. Less information can be incorporated into the GI for a small screened computer since part of the application window will be covered over by it.

- Cognitive level. There is a cognitive effort in understanding that handling an input device produces a change on the computer screen. The method of initiating a task should be intuitive since some people may not be capable of much encoding.

"Computer Access" (CA) describes the need to map a user's input to the computer's functionality. The traditional approach is to interpret alternative input devices in such a way as to emulate the standard input devices (See Fig. 1 a). Although this approach seems intuitive, it makes the assumption that such users are best able to access computer functionality through the same channels as an able bodied person. In fact, the approach serves only to make it cumbersome to access the capabilities of computer software (1,2).

Traditional mouse emulation, in particular, can be very cumbersome, such as when using a four switch array to generate mouse movement. Choosing a menu command is accomplished by a series of switch closures to manoeuvre the mouse to the appropriate locations in the menu. The same task could be accomplished more directly in several ways, one way would be to activate one switch with a special code to access the menu bar (Morse code for m, for example), then activate the switch to select the column (four times for the fourth column) and then again to select the corresponding row of that column (three times for the third choice).

In our minds, alternative access systems should "access computer functionality" (Fig. 1 b) rather than "access keyboard and mouse" (Fig. 1 a), contrary to the traditional approach discussed above.

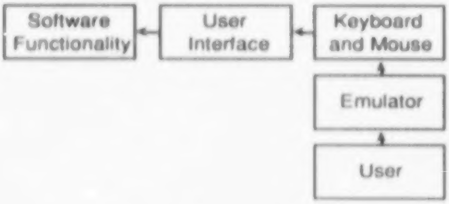


Figure 1 a: Traditional approach

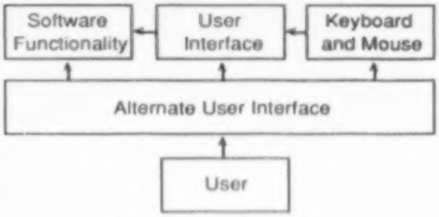


Figure 1 b: Direct approach

Statement of Problem

The problem is to design a system which will allow the specification of appropriate ways for physically handicapped persons to drive a computer more directly. This system can be tailored to the individual according to the design issues discussed above by customizing the physical input method and the graphical interface.

The present user interface implemented on the Macintosh is not satisfactory since we want to deal with more information than just keyboard and mouse emulation. A new user interface must be incorporated which will allow the definition of user interfaces of a different nature. Taking this approach will result in a new input and user interface "foundation", rather than the traditional one which is based only upon keyboard and mouse.

Approach

We must consider new variables in the specification of interfaces appropriate for limited input users so more information can be extracted from that interface. For instance, time can be used as an extra control variable to get more information out of one switch. While scanning with a single switch it may be feasible for the user to hit the switch with a special code to escape out of an incorrect group selection. This eliminates having to wait for the computer to scan through the incorrect selections. The usefulness of this option will be determined by the cognitive and physical ability of the user.

It is possible to use an arbitrary number of alternative input devices. These inputs may include all standard inputs (keyboard, mouse) as well as a variety of alternative access devices. We must reduce the set of all activities the user would wish to choose from to a simple set of functions which depend on the current application.

The software has two parts, an input engine and an output engine (See Fig. 2). Input received by the input engine falls into two categories: physical device actuations, called input triggers, and context, called context triggers. Context triggers allow the meaning of input to be dependant upon the current state of the machine, or, in other words, what the user is currently doing. "Output triggers" going from the input engine to the output engine can be defined as a function of any combination of the input triggers, including historical information. For instance, an output trigger defined to select from a scanning keyboard could be specified to become true whenever the user closes a switch for at least 500ms but not more than 1000ms. With two or more input devices, endless combinations of triggers can be defined, depending upon the specific capabilities of the user. Any conceivable form of switch input can be handled such as Morse code, obscure combinations of multiple switches or a single switch input having many meanings depending upon the state of the machine. In this manner, the input engine can be extended to make limited input richer.

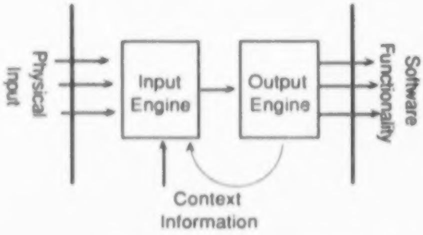


Figure 2: Approach to Computer Access

Next, the output engine must make a decision as to what to do with the given input. The input engine has no channel to communicate to the user since it is a low level operating system extension which acts as a black box control centre. Within the output engine, the author may use three channels to communicate options to the user: audio, a window (GI) and cursor. By selecting these options, the user may implement software functions, change the meaning of future input, or control the interface itself. For instance, the cursor channel of communication may display a spinning cursor which moves in the direction indicated when the switch is closed.

The software has been implemented as a system extension and MultiFinder ™ background application. This allows it to function concurrently and interact with existing Macintosh software.

The discussion of specific software functions and the exact nature of input devices from a hardware and software standpoint are not within the scope of this paper.

Implications

Today's advanced computers, including the Apple Macintosh, rely upon "high input bandwidth" since they allow such a rich set of input options at any given time. The input engine's contribution is to allow alternative input devices to be extended to whatever manner the user is capable of driving them in order to overcome this lack of rich input. Thus, a well designed set of triggers will maximize whatever input bandwidth is available.

The GI can channel input most appropriately towards performing a task. Essentially, different sets of options are made available to the user at different times and even more options are made available through word prediction and macros. This is an example of the computer doing more work to bring appropriate options to the user so that communication speed from the user to the computer is increased. Thus, the computer is generating a high output bandwidth.

To make the computer even more directly accessible to the user in the future the next step will be to create a set of "templates" specific to every application, window or task so that the options which the user may choose from are appropriately limited. For instance, when a dialogue is presented to the user which asks, "Do you wish to save this document before quitting", it is evident that the user need only indicate the answer to this question, there is no need for the interface to offer options such as moving the mouse, typing text, or anything else. A template will allow the user to choose directly from options, rather than working through the cumbersome and time consuming abstraction of moving a mouse or typing on a keyboard. This final mechanism reduces the set of options presented by the output engine so that the user may choose what he or she wants with fewer actuations chosen via the input engine.

Discussion

Obviously, this system has implications for any mode of alternative access method: headpointer, single switch, expanded keyboards, etc. A concrete example is presented here for clarity. Morse code is a very fast way to enter text with single or dual switch access and is chosen by many users who have the dexterity and cognitive level to practice it. There are an overwhelming number of codes to remember if punctuation, control characters, and macro codes are to be used in addition to letters and numbers. It would be easier on the user if the complicated codes, or even alphanumerics they cannot remember, could be accessed from a scanning graphical interface. Then the user would have redundant methods of accessing the same thing (2). It is not a trivial exercise to switch between morse code and scanning input on traditional systems, however, with our design these two methods can be used easily side by side. Word prediction and macros can also be presented in the graphical interface to help speed up access time for the user. A graphical interface which expresses the ideas discussed here is shown in Figure 3. The GI scans between the word prediction list and the activation areas which summon other scanning levels or macros. Icons are used to represent other scanning levels for numbers and punctuation, alphanumerics, and modifier keys and macros to initiate the spinning cursor, menu access, and page up/page down.

The manner in which the user accesses these graphical interfaces can be adapted exactly to the user. If the user has the physical dexterity to utilize more than the one or two switches that are required by morse code this extra degree of freedom can be utilized. The third switch could be used to start scanning the graphical interface, and then select items. After the word prediction list is selected a specific word can be chosen directly, for example, if the third item down was required they could hit the switch three times in succession.

This system seems so flexible that it is almost overwhelming. In order to be functional in the real world it must become very user friendly. To accomplish this several standard keyboard layouts will be provided with the option to adapt them to specific users. An expert system should be developed to help the therapists and users to make the best choices for access method, graphical layouts (4) and useful macro functions.

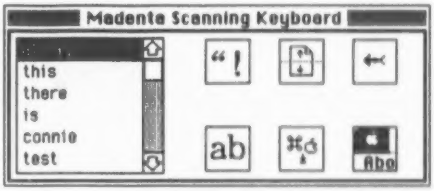


Figure 3: Sample Scanning Layout

Acknowledgements

This research was funded by an IRAP-M grant from the National Research Council of Canada

References

(1) Brownlow, N., Shein, F., Terviranus, J., Milner, M., Parnes, P., (1990). 'Don't Manipulate, Delegate!' *Proceedings of the RESNA 13th Annual Conference*, pp. 153-4. Washington: RESNA Press.

(2) Hill, David R. (1987). 'Interacting with Future Computers', *Future Computing Systems*, (Oxford University Press and Maruzen Company Limited), Volume 2, Number 1.

(3) Robert, Jean-Marc, (1988). 'Computer User Acceptabilty for Disabled People.' *Proceedings: International Conference of the Association for the Advancement of Rehabilitation Technology*, pp. 612-4, June 25-30, Montreal, Canada.

(4) Shein, F., (1988). 'A Prototype Expert System for the Design of a Visual Keyboard'. *Proceedings: International Conference of the Association for the Advancement of Rehabilitation Technology*, pp. 374-5, June 25-30, Montreal, Canada.

Kim Adams
Madenta Communications Inc.
#129 Advaced Technology Centre
9650 20 Ave.
Edmonton, Alberta, Canada, T6N 1G1

5.5

THE CONTROL INTERFACE ASSESSMENT SYSTEM: A COMPUTERIZED ASSESSMENT TOOL TO EVALUATE CONTROL INTERFACE DEVICES

Cindy L. George, Warren E. Lacefield, & Barnard P. Fleming
Academic Software, Inc.
Lexington, KY 40507

ABSTRACT

This project develops and fieldtests a prototype software/hardware assessment package to support assistive technology assessment personnel responsible for selection of appropriate control interface devices for persons who have difficulty interacting with their environment. This population includes individuals with learning, intellectual, or physical disabilities; very young persons; and/or elderly persons. The *Control Interface Assessment System* (CIAS) includes software designed to measure critical characteristics of an individual's ability to interact with available and potentially useful control interface devices such as touch keyboards and adaptive switches. The CIAS system is compatible with IBM computers and utilizes two specially designed control interface devices: a Membrane Keyboard Simulator (MKS) and a Universal Adjustable Microswitch (UAS). These devices connect to the computer and are operated by the individual following a series of standardized test sequences under software control using visual, auditory, and kinesthetic prompting. CIAS is intended to provide the capability to simulate a wide array of specialized control interface devices prior to a decision to acquire any particular one and improve the accuracy of assessment procedures for determining appropriate devices for environmental control.

BACKGROUND

Current advances in technology have made independent environmental interaction a feasible goal for persons who previously have been unsuccessful in controlling their environment. Advances have been made in the development of specific devices and equipment needed by these individuals as well as the development of alternate control interfaces for existing devices and equipment. An *interface* provides the means for interaction to occur between the user and an object (Levy, 1983). The relatively new application of physical and electronic control interfaces in the rehabilitation/habilitation and special education fields is providing many persons first-time experience with various forms of environmental control (i.e., playing with toys, turning on lights, using microcomputers, controlling scanning displays, and communicating through the use of augmentative communication devices).

A wide variety of alternate control interface devices are commercially available. These devices are included in categories such as microswitches, alternate keyboards, mouse keyboard emulators, speech recognition systems, and environmental control units. The TRACE Center published a Rehab/Education Resource Book Series in 1987 that provided a comprehensive catalog of 117 adaptive switches as well as a wide variety of other adaptive interface devices.

STATEMENT OF THE PROBLEM

The assessment process for making decisions regarding control interface devices has become increasingly more difficult as the number of device options increase. When variations in physical dimensions and operational characteristics for these basic types of microswitches and other variations in user functionality and positioning are considered, the list of possible choices for a particular individual and functional task becomes bewildering even to the most experienced assessment professional. The question becomes *Which of the many control interface devices is appropriate for which user?* Just as user abilities and limitations vary, so do control interface device variables and dimensions. The importance of determining the appropriateness of a device by matching the user with a control interface device is crucial to providing users with *their key* for interacting with the world.

RATIONALE

Assessments must be developed to address not only the specific needs of the population but also the range of individual differences found within that population (Glennen & Ourand, 1989). The need for systematic assessment methodologies is clear in the current literature (Esposito & Campbell, 1987; Wright & Nomura, 1987). Assessments for control interface devices are currently being conducted using a wide range of procedures. Decisions that are made regarding which device is predicted to be most effective and efficient for a particular user are often based on subjective data only. Professionals conducting assessments are often limited to making judgments based on direct observations. To make assessments more accurate and reliable in terms of *rate* and *duration*, stopwatches and other timing devices have been used. Oglesby states that other variables such as *actuating force* and *travel* are equally significant to the assessment process and should be addressed (1987). However, these variables are not as easily measured and seldom are included in assessment reports.

The number of control interface devices available to any one assessment lab or clinic is limited by the high cost of commercially available devices. It is unrealistic to expect that an assessment lab/clinic could possibly be equipped with the range of interface devices needed to adequately assess which one of the vast number of commercially available devices a user actually needs. Professionals conducting technology assessments are forced to use the specific control interface devices they have at hand to evaluate a user's performance. Using this technique, professionals can not make reliable recommendations that some alternate control device (other than the one they actually used during an assessment) would be more appropriate since the alternate device was not tested directly by the user. Consequently, this assessment technique is limited by its recommendations of only those specific control interface devices available for use and used during an assessment.

Additional assessment tools currently being used by professionals include specialized microcomputer software programs (Single Input Control Assessment, 1983; Rizer, Rein, & Ourand). These computerized assessments provide professionals additional means of gathering reliable data by electronically measuring the variables *rate* and *accuracy*. Current computer programs, like the other assessment procedures previously described, have limitations for they too do not address all of the variables needed to accurately assess control interface devices. Furthermore, existing software programs do not allow for the range of commercially available devices.

An assessment tool which can be altered and adjusted to match the varied range of users' abilities with control interface device variables as well as their dimensions is badly needed. Creating a microcomputerbased assessment system which would measure the abilities of the user in terms of actuating force as well as travel, would improve assessment procedures by calculating the specific variables needed in a control interface device for the user to be successful. In addition to addressing both the user and device variables, a computer assessment system that would eliminate the need for purchasing a wide array of commercially available control devices would be quite cost-effective. The Control Interface Assessment System meets this need.

DESIGN & DEVELOPMENT

CIAS is a software/hardware package written in the C programming language to facilitate porting the source code to different microcomputer systems. The current version of the CIAS software will run on the IBM PC microcomputers (and compatibles). The hardware devices required as part of the assessment package are designed to interface with the IBM system. Assessment professionals using CIAS software will be asked to provide general information about the user which includes the user's name, assessment date, and specific information about the particular device being assessed (i.e., the anatomic site used to activate the switch, the position of the switch, the size of the grid of cells on the keyboard). Next, professionals are given the option to assess two major categories of control interface devices: switches and membrane keyboards (alternate keyboards for microcomputers as well as keyboards on dedicated communication devices). Within each major category, a variety of tests are available as options for assessing that particular device. Testing options allow for the ability ranges of the persons being assessed.

Two specially designed general purpose control interface devices that have been developed are the membrane keyboard simulator (MKS) and the universal assessment switch (UAS). Both these devices use force sensing resistors (FSR) technology for continuous measurement of the actuating forces (Interlink Electronics, Santa Barbara, CA; Hyman and Miller, 1990). The mechanical design of the UAS allows it to simulate and substitute for all the various pressure-sensitive switches usually used during an assessment. The switch is designed to accept contact surfaces varying in size, and shape, and texture. A specific force for successful switch closure can be preset by the professional. The MKS is constructed of a two-dimensional array of 384, 3/4" FSR. The array consists of 16 rows and 24 columns. The dimensions of the MSK is 18" x 12". Each FSR is positioned to reduce "dead zones". A thin plastic sheet overlays the FSRs to provide even distribution of force as well as protection. An A/D converter is interfaced to the IBM performing the final processing of data from either the UAS or MSK.

EVALUATION

The CIAS evaluation will be completed in the spring of 1991. Plans for this fieldtest encompass three phases. The first phase involves in-house evaluation to validate the accuracy of the software system for measuring and calculating variables tested by the CIAS hardware assemblies. Software measurements obtained using the MKS and the UAS will be compared to similar measurements obtained using six commercially available pressure switches varying in terms of rated travel and actuating force variables.

The second fieldtest phase will be conducted to evaluate the CIAS testing content. It is crucial that the various tests that are provided as options for assessing a user's abilities to interact with the UAS and the MKS well represent the many available control interface devices that can be recommended for use. Need for additional or altered test sequences and/or content will be identified at the time of evaluation and field testing. The targeted group for evaluating the system content will be representatives from groups who are responsible for instructing others about the availability and use of control interface devices. Three questions will address the content of the CIAS. 1) Are the interface tests appropriate for assessing the user's ability to use a membrane keyboard and/or use a switch to interact with their environment? 2)Are there any changes in the existing tests that would provide a more accurate demonstration of user abilities? 3)Are there any additional tests that could better assist in assessing user's abilities?

The final fieldtest phase will involve the use of the CIAS for actual assessment work with professionals within the first nine states which were awarded assistive technology funds through *The Technology-Related Assistance for Individuals with Disabilities Act of 1988* (PL 100-407). The states that were awarded funds to provide assistive technology information, assessment, and devices to persons within their respective borders are: Arkansas, Colorado, Illinois, Kentucky, Maine, Maryland, Minnesota, Nebraska, and Utah. Each state's lead agency will be contacted and asked to identify a state assessment site. The assessment site will conduct at least two actual assessments within the week (5 working days) that they are provided with the CIAS software/hardware package. Sites will provide information and evaluation feedback to the project staff concerning at least three major issues: (1) the effectiveness of the Control Interface Assessment System with regard for assessing user abilities and providing assessment professionals with information that is useful when purchasing commercially available interface devices for the user; (2) the utility of the general discussion, operation instructions, and tutorials contained in the CIAS User's Manual; and (3) the effectiveness and suitability of the software presentation formats, display screen appearance, user prompting modes (visual, auditory, and kinesthetic); user interface characteristics, including positioning, motivation; and and ability to work with the control interface simulators. These issues are reflected in the following evaluation concerns that will be addressed during the evaluation.

A major factor to explore in the evaluation is whether assessment professionals can reliably and easily assess users' abilities to interact with control interface devices. Three questions relate to the suitability of the system utility for its intended purposes: 1) Are assessment professionals able to use summary information that is displayed following testing procedures? 2) Are the summary information printouts useful in providing additional documentation for assessment reports? 3) Is the summary information appropriate and accurate in assisting the assessment professional in the decision making process for purchasing commercially available control interface devices?

In addition to results provided using the CIAS, it is also important to determine whether the software is presented in a way that makes it easy to understand and operate as well as whether the hardware is designed in such a way that it is easy to manipulate. The informations contained in the draft User's Manual and other documentation and the actual presentation formats and flow-of-control for the software itself will need to be tested in the field. Errors that may exist in both the software program execution and display of information and the manipulation of the customized hardware devices are also identified at this time. Ten evaluation questions are related to the concern about software and hardware design and operation: 1) Are instructions for using the system appropriate, sufficient, and clear? 2) Are the format of screen designs and method of presentation clear? 3) Is the level of language appropriate? 4) Are unique terminology and technical terms well-defined? 5) Is the sequence of information that is presented appropriate? 6) Are there any typographical, grammatical, or other mechanical errors in the screen display? 7) Are the supplementary materials sufficient? 8) Is the system easy to set-up in terms of interfacing the hardware devices with the microcomputer? 9) Are the Universal Switch and the Membrane Keyboard Simulator appropriate for assessing control interface devices? 10) Are the hardware devices easy to manipulate?

Like the second phase of fieldtesting, it is crucial that the various tests that provided as options for assessing a user's abilities to interact with the UAS and the MKS well represent the many uses for recommending the use of control interface devices. The need for additional or altered test content are identified at the time of evaluation and field testing. Three questions will address the content of the CIAS. 1) Are the interface tests appropriate for assessing the user's ability to use a membrane keyboard and/or use a switch to interact with their environment? 2) Are there any changes in the existing tests that would provide a more accurate demonstration of user abilities? 3) Are there any additional tests that could better assist in assessing user's abilities?

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Instituteof Child Health and Human Development under Grant Number 1-R43-HD27411-01. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views or policies of theNational Institutes of Health.

REFERENCES

Eposito, L. & Campbell, P. H. (1987). Computers and severely and physically handicapped individuals. In J. D. Lindsey (Ed.), Computers and Exceptional Individuals (pp. 105-124), Columbus: Merrill.

Fishman, I. (1987). Electronic Communication Aids: Selection and Use. Boston: College-Hill.

Glennen, S. & Ourand, P. (1989 October). Technology assessment. Evaluation of Computer Input Methods for Persons with Physical Disabilities. Presentation conducted at the Seventh Annual Closing The Gap Conference: Microcomputer Technology in Special Education and Rehabilitation, Minneapolis.

Goldsbrough, T. L. & Rayner, J. (1983). Analog Electronics for Microcomputer Systems. Indianapolis: H.W. Samms and Company.

Horowitz, P. & Hill, W. (1988). The Art of Electronics for Microcomputer Systems. New York: Cambridge University.

Hyman, W.A. & Miller G.E. (1990). Application of force sensitive resistors. RESNA, Proceedings of the 13th Annual Conference, 201.

Levin, J. & Scherfenberg, L. (1986). Guidelines for the use of automated learning devices by persons who are multiply handicapped. In M. Donath and Others (Ed.), *Proceedings of the Ninth Annual RESNA Conference* .(55-57).

Levin, J. & Scherfenberg, L. (1987). Selection and Use of Simple Technology in Home, School, Work, and Community Settings. Minneapolis: AbleNet.

Loeb, K. M. (1983). Membrane keyboards and human performance. *Bell System Technical Journal*, 62(6), 1733-1749.

Oglesby, C. (1987). Activating Switches.

Sheingold, D. H. [Ed.] (1981). Analog devices. Transducer Interfacing Handbook. Norwood, MA.

Single-Input Control Assessment. (software package) (1983) Microcomputer applications Programme, Ontario Crippled Childrens' Centre.

Wright, C. & Nomura, M. (1987). From Toys to Computers: Access for the Physically Disabled Child. San Jose.

Levy, R. (1983). Interface modalities of technical aids used by people with disabilities. *The American Journal of Occupational Therapy*, 37 (11), 761-765.

Rizer, H., Rein, J. J. & Ourand, P. (????). Assessment of Interface Control for Direct Selection Techniques [Computer Program]. Rockville, MD: The John Hopkins University, Division of Education and The Maryland State Rehabilitation of Education Division of Vocational Rehabilitation: Maryland Rehabilitation Center Technology Resource Office (NIHR Grant #G00853C506).

TRACE Center Rehab/Education Source Book Series, Volume 2: Communication, Control, and Computer Access for Disabled and Elderly Individuals: Switches and Environmental Controls. (1987) College Hill Press, Boston.

Cindy L. George
Academic Software, Inc.
331 West Second Street
Lexington, KY 40507

IMPROVING ALTERNATIVE ACCESS TO COMPUTER GAMES

Glen Ashlock

Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation,
University of Michigan Medical Center

ABSTRACT

Alternative computer access methods such as scanning and Morse code can be used by people with handicaps to play computer games. Customized input systems increase the number of games that can be played using these methods and reduce the effort needed to play them. A set of guidelines for creating customized access systems is developed and examples using these guidelines with a commercially available keyboard emulation program are presented for two different games. A case study that demonstrates a clinical application of playing computer games is also presented.

BACKGROUND

Playing computer games provides a means of recreation and serves to introduce new users to computers and experienced users to a new access method. For new users that are intimidated by computers, playing games can help them to overcome their initial fear and ease them into learning the operating system. Game playing can also be used as a way to maintain a user's interest while providing the needed practice and repetition necessary to become proficient using a new access method. Computer games also provide a way for people with handicaps to play and compete with friends and family, both disabled and non-disabled. Computer games are a recreational activity that can be resumed quickly after an injury, often with the user at the same skill level as before his or her injury. In addition to these other reasons, playing games is just plain fun.

Access methods such as scanning and Morse code provide an alternative to using keyboards that works well for many applications, such as word processing, but in many cases these methods are not very effective for playing games. Using scanning in most standard configurations forces the user to repeatedly scan past characters that will never be used for the game. Another problem is that games often require combinations of letters, numbers, and arrow or function keys. These keys are typically on different levels of the scan tree, so the user spends a lot of time switching levels instead of playing the game. Since speed and timing are important while playing many games, these delays may make a game impossible to play using scanning in a standard configuration. Since Morse code is a direct select method, it does not involve the same problems as scanning. However, for games where speed and timing are important, entering the code for a key may take too long, especially for new users.

OBJECTIVE

This paper presents a method of improving access to computer games for handicapped individuals. A set of guidelines for using customized scan trees to play computer games is developed and demonstrated with examples from two games and a brief case study.

METHODS

Only a limited set of keys is required to play most games, and a small subset of these keys may be all that is necessary at a given level of the game. Some characters may be needed throughout the game, while others are needed only on a few occasions. When using scanning input to play games, a scan level that contains only the necessary characters for the current game level reduces the probability of selection errors and minimizes selection time. The arrangement of the scan trees should be determined by the flow of the game, changing automatically based on the keys selected to match the current game level.

The entries (selection choices) in each scan level should be arranged by their frequency of use. The frequency of use for each entry is generally dependent on the current level of the game. To minimize selection times, the order of the entries within the scan level can be changed automatically, based on the previous selection choices. It should be noted, however, that frequent changes in the arrangement of the entries in a scan level may offset the gain in efficiency realized from optimizing the order of the characters(1). This is because dynamic ordering of entries in a scan level increases the cognitive load on the users and requires them to spend more time visually searching the choices on that scan level for the desired entry. The abilities of the intended user should be considered before making use of dynamic scan trees.

There are instances during a game when is helpful to enter multiple characters and perform other functions. For example, there may be a need to repeat a particular keystroke many times in a row or to enter a frequently used combination of keystrokes. It may also be helpful to change parameters such as the speed of the game. It should be possible to execute these tasks by selecting one item in a scan tree or by entering a single code when using Morse code. To do this, the alternative access method must allow the creation of an item in a scan tree or a Morse code sequence that changes scan tree levels, enters strings of characters, performs system functions, or executes any combination of these actions. For Morse code, this requires the ability to define special codes that are not included in the standard Morse code set.

When using scanning as the input method, the input rate and timing are determined by the scan rate and position of the item within the scan level. For Morse code, input rate is determined by the speed at which the user can enter the codes. When the timing of the keystroke is critical to the game, a specialized scan level that contains a single entry can be used. With this type of scan sublevel, the entry is input whenever the select switch is activated. When using Morse code, the access method should allow a code to be defined that will switch the user into scanning mode with a single-entry scan level. As with scanning, the keystroke is input when the select switch is activated. The single-entry scan level should be configured so that it returns the user to the previous mode after a preset number of selections have been made or a wait period is concluded.

As an additional note, individuals using the MS-DOS or other appropriate operating system can create a batch file that allows users to independently switch between the custom scan tree for a game and their standard configuration for other applications. The command to start the batch file is entered with the user's standard input method. For the handicapped user to be independent, the batch file needs to change to the input configuration for a particular game, run the game, and then return to the user's standard configuration when the game is completed.

RESULTS

The keyboard emulation program used to develop the following methods and examples was Altkey(2,a). Altkey was selected because it allows a great deal of freedom in the design and utilization of customized scan trees, Morse code with user-defined codes, and combinations of Morse code and scanning.

Game 1

Magic Boxes(b) is a math game where the user completes equations in rows and columns by adding numbers and math symbols. The necessary keys are the numbers, +, -, x, the arrow keys, and a few letters and function keys that are used for game commands. The only keys required in the scan level for the game set-up screen are the numbers 1 to 8 to select the level of play and the Esc key to quit. The "easy" game levels use either the numbers or the math symbols, so only one of these groups is needed in the same scan level. The initial scan level is set up so that when one of the "easy" game levels is selected, only the appropriate group appears in the resulting scan level. The arrow keys are the most commonly used group of keys throughout Magic Boxes and are positioned at the beginning of the entries in the scan level used to play the game. After an arrow key is selected to move the cursor in a given direction, it is likely that the next movement will be in the same direction; that arrow then moves to the front of the arrow group in the scan level. Since the numbers and math symbols are the next most commonly used groups, they follow the arrow group in the scan level. Any of the game control commands may be needed throughout the course of the game, so the command group is always available. However, since none of these commands are used very often, the command group is the last group in the scan level. The individual commands in the group are arranged by their frequency of use.

Game 2

The game Mean 18(c) simulates playing a round of golf on one of several well-known golf courses. Before making a shot, the arrow keys can be used to adjust the direction in which the ball will be hit. When putting, this often requires pressing the key as many as 30 or 40 times in a row. To simplify this process, special codes were defined that enter up and down arrows in groups of 5 and 10. There are three steps needed to hit the ball in Mean 18. Pressing the spacebar starts the backswing; pressing it again determines how hard the ball will be hit by stopping the backswing; and the third press determines the accuracy of the shot—a little too early and it hooks, a little too late and it slices. A special scan level is initiated after the shot has been lined up and a club selected using either audio scanning or Morse code. This special scan level consists of three levels, each with "space" as the only item. After the third "space" is selected, the system returns to the user's regular mode until he or she is ready for the next shot.

Case study

H.J. is a 32-year-old woman with ventilator-dependent quadriplegia as the result of a sports accident in 1969. H.J. had not previously used a computer, but was interested in learning how to do so, primarily for writing. Based on her abilities and goals, two-switch Morse code was determined to be the best long-term access method. Initially, she had difficulties entering the proper codes and her attempts at writing became very frustrating. To provide her with a break from word processing, H.J. started playing the Mean 18 golf game using Morse code. Her input error rate was just as high in golf, but unlike word processing, entering the wrong code usually did not have the result of inputting a character that needed to be deleted. After playing the golf game for several sessions, H.J.'s input error rate had decreased and she returned to the word processing program. During this later attempt at writing, she was able to enter text at a much higher rate with fewer errors. H.J. continued to increase her input rate by practicing Morse code using both the word processor and the golf game.

DISCUSSION

Customizing alternative access systems increases the number of computer games that can be played by people with handicaps, but problems still remain that prevent the methods discussed above from being used with some popular games. Some games require the user to quickly enter several different keystrokes, each time in different combinations, so a custom scan tree cannot be created in advance. Morse codes can have up to 6 dots or dashes for each keystroke, so even fast users will be at a disadvantage in these types of games. Another problem is that games which run in graphics mode often cannot be used with on-screen scanning because the entries in the scan trees are badly distorted or not visible at all. These methods also do not provide access to games that require mouse or joystick input, although other options, such as head-controlled pointing devices, are available.

ACKNOWLEDGEMENTS

The author wishes to thank Simon Levine and Lincoln Jaros for their assistance with the preparation of this paper.

REFERENCES

1. Horstmann HM, Levine SP, Jaros LA: Keyboard Emulation for Access to IBM-PC-Compatible Computers by People with Motor Impairments. *Assistive Technology*, Vol. 1(3): pp. 63-70, 1989.

2. Horstmann HM and Levine SP: Modeling of User Performance with Computer Access and Augmentative Communication Systems for Handicapped People. *Augmentative and Alternative Communication*, Vol. 6(4): pp. 231-241, 1990.

MANUFACTURERS

a. Altkey
Baylor Biomedical Services
3707 Gaston Ave., #216
Dallas, TX 75246
214-820-2176

b. Magic Boxes
Softdisk, Inc.
Published on Big Blue Disk #34
1-800-831-2694

c. Mean 18
1986 Accolade, Inc.
Microsmiths, Inc.

ADDRESS

Glen Ashlock
Rehabilitation Engineering Program
1C335 University Hospital
Ann Arbor, MI 48109-0032

5.7

The Universal Access System and Disabled Computer Users

Neil G. Scott
Universal Access System Project, DVSS
California State University, Northridge
Northridge, California USA

Abstract

This paper describes a new approach to making computers accessible to persons with disabilities. Developed at California State University, Northridge, the Universal Access System enables an individual to operate any computer over an infrared communications link. The system breaks away from usual access methods by performing all access functions outside the computer which runs the application. Applications programs run on a host computer, and all access functions are handled within a personal access device called an "accessor." This separation of functions eliminates many of the problems and limitations inherent in present access systems. Additionally, the Universal Access System has the potential to significantly lower the cost of providing access.

Introduction

The Universal Access System equalizes accessibility to use any computer, appliance, or electronic device. Traditionally,disabled individuals require a host computer to run special access programs as well as applications. The Universal Access System performs all special access functions outside of the host in a personalized "accessor." In other words, the host computer runs the application and the accessor provides the access. Host computers no longer need to be modified in a user-specific manner. Instead, they are made accessible through the addition of a low-cost, standardized "Universal Access Port." This port provides an interface between the resources of the host and the "Universal Access Link." Any accessor can communicate with any suitably equipped host. In simplistic terms, an accessor can enter information into a host program as if it were coming from the host keyboard or mouse, and read information from the host screen. A host has no knowledge of how information is generated or used within an accessor.

Potential benefits of adopting a Universal Access System include:

- **Budget Stretching** – The Universal Access System is cost-effective for disabled users and organizations which must provide accessible equipment. On one hand, a personal accessor provides a disabled individual with access to any device equipped with a Universal Access Port. On the other hand, educational institutions, employers and public service providers can make their information processing equipment accessible for a very small unit cost.
- **Durability** – Individual solutions based on the Universal Access System are more durable than present solutions. The accessor doesn't need to be changed as a person's study or work requirements change. An accessor correctly matched to an individual's requirements will remain valid for a very long time, thereby leading to significant savings in assessment, counseling, engineering, and training resources.
- **Setting Standards** – Adopting standards based on the Universal Access System will make the manufacture of special access equipment more viable because it will lead to increased market sizes.
- **Compliance with ADA and Section 508** – The Universal Access System provides the most straightforward and lowest cost method to comply with federal access requirements such as the Americans With Disabilities Act.

The Universal Access System can fully utilize currently available special access products. In fact, incorporating the Universal Access Link protocol into existing products will increase their utilization as they automatically inherit the ability to interact with any other Universal Access System device.

Universal Access makes any device that uses electronic control accessible. In some cases, a Universal Access Port will be included as part of the controlled device. ATMs, telephones, home appliances, and elevators, could easily include a Universal Access Port. In other cases, interfacing will be possible through an intermediate standard such as CEBus, which was developed to provide remote control in homes and industrial plants. The same accessor that enables a person to write can provide full access to environmental control through its interface to the CEBus.

Prototypes of the Universal Access System are currently being evaluated and demonstrated to interested organizations. Production and marketing of the Universal Access Link and a selection of accessors is underway. Software drivers for connecting the Universal Access Port to a host have been developed for IBM compatible and Apple Macintosh PCs. Drivers for other computers and a more extensive range of accessors are planned for development over the next year.

Traditional Access Methods

The unique approach of the Universal Access System becomes apparent by briefly reviewing traditional approaches to providing computer access for disabled users. At the present time, it is usually necessary to modify the host computer in a user-specific manner, providing special hardware, software or both. While this approach is generally satisfactory for disabled individuals who work with a single computer, it is a major problem for institutions in which many computers must be used by many different people. For example, California State University, Northridge has nearly four thousand computers which should be accessible to all students. However, with a disabled population of almost one thousand, it is not possible to predict where and when particular types of access will be required. Our present solution is to provide services at a centralized Computer Access Lab. This lab contains about thirty computers and a selection of special hardware and software. Each disability is handled by one or two specially adapted systems. While this lab has achieved its basic aim of assisting disabled students, it is not the perfect solution. Students are restricted to working in the lab, suffering inconvenience and unable to work alongside their peers. They often have no access to certain programs. One solution is to equip disabled individuals with an accessible laptop computer they take to class. While this works in some situations, there are some severe limitations in its effectiveness. Many of the required programs cannot be run on a laptop computer because of memory size, operating speed, storage requirements, lack of particular peripheral devices, or copyright restrictions.

The Universal Access System Concept

The Universal Access System builds on the idea of equipping disabled individuals with an accessible laptop computer; not to run applications programs in the laptop, but to use the laptop as an extension of a host computer's screen and keyboard. In this case, the laptop computer is referred to as an accessor. The interaction between an accessor and a host is such that the accessor handles all user-specific requirements. Communication between an accessor and a host computer is provided by a bi-directional, wireless, infrared data link called the Universal Access Link. It is this link which enables the Universal Access System to work with any type of host and any type of disability. At one end, the Universal Access Link connects to a host computer through a Universal Access Port. At the other end, an accessor provides the interface to a disabled person. Equipped with an appropriate accessor, a person can access any computer which has a Universal Access Port. The various requirements of individuals with different disabilities are met by using different accessors.

It is an option, not a requirement, for an accessor to use a laptop computer. An accessor can be as small or as large as is necessary to handle the access requirements. For example, a "Morse code accessor," can be constructed from single chip microprocessor at a cost of a few hundred dollars. In contrast, a "speech accessor" capable of taking dictation requires a fast 386 computer with eight Mb of memory and a hard disk and costs more than ten thousand dollars. Between these extremes, there are many situations in which a standard laptop computer will provide the most cost-effective solution. An important factor, however, is that *each of these accessors can operate the same host computers without any changes being made to the host.*

The following example shows the value of the Universal Access System: With the traditional approach, a computer to be used by a blind person is equipped with a text review program and a speech synthesizer. While this makes the computer accessible to the blind user, it does nothing for physically or learning disabled users. Separate modifications are required to handle each type of disability. No such limitation exists for the Universal Access System. All computers capable of interacting with the Universal Access Link present an identical interface to accessors. Personal accessors handle the great variety of capabilities required by individuals with different disabilities. For example, accessors for blind users contain a speech synthesizer and software for reading the host computer screen. Accessors for physically disabled persons use pointing, Morse code or scanning to enter keystrokes into the host computer. Individual accessors are programmed to select only those features of the host they are replacing or augmenting. So, accessors for blind or visually impaired users read the screen of the host and either magnify or speak the text. Accessors for physically disabled users will generally send information to the mouse or keyboard of the host and not need to read the screen. An accessor for a person who is blind and physically disabled might include all three of these capabilities.

Description of the Universal Access System

The Universal Access System consists of four basic components: An acccessor, a Universal Access Link, a Universal Access Port, and a driver program which runs in the host computer.

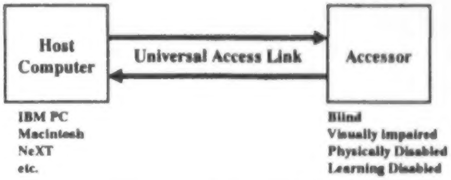


Figure 1. Universal Access System

- **Accessor** – A bridge between the special needs of a disabled individual and a standardized communications protocol supported by the Universal Access Link. Accessors can be designed to support any form of input or output that may be required by a disabled user. Accessors may be very simple; i.e. a Morse code generator, or they may be very complex, i.e. a speech recognition system.

- **Universal Access Link** – A bidirectional, infrared link which gives access to the standard input and output functions of a computer. The same link protocol is used for all computers and accessors, and is built around a packet system in which standard packet structures transport data back and forth between the accessor and the host computer. Packets are defined for keyboard events, mouse events, screen events, and miscellaneous events such as file transfers. The link uses interrupts to interact with the accessor and host computers only when there are packets of data to be transferred. This ensures that the link has no effect on the performance and resources of the host computer when there is no accessor present.

- **Universal Access Port** – The physical connection to the host computer. The present design consists of an infrared transceiver which plugs into a serial port on the host computer. As the Universal Access System matures, we expect the Universal Access Port to be included as a standard feature on most computers.

- **Host Driver Software** – A bridge between the standardized protocol of the Universal Access Link and the specific hardware and software requirements of a particular type of computer. Each computer type requires a single driver program to enable it to function with the Universal Access Port. The functions performed by the driver include: link management, management of data packets (assembly, routing and disassembly), and interfacing to keyboard, screen and mouse resources. Once a driver has been written for a particular computer, all accessors are able to use that type of computer.

Cost Considerations

Compelling reasons for adopting a Universal Access System are that it provides better utilization of resources and it disabled individuals a much higher level of independence.

Traditional approaches for providing access are costly because each computer used by a disabled person must be equipped with whatever special hardware and software is necessary. The adaptations are usually non-portable since they cannot be easily moved back and forth between computers at home and at work, for instance. In contrast, a Universal Access Port can be attached to a computer for no more than a few hundred dollars and the same accessor can be used with computers at home, school or university, and work.

The cost of providing access goes far beyond the purchase of a particular item of hardware or software. Labor costs include evaluations, development of suitable solutions, funding, and training. Furthermore, many of these costs are repeated each time a disabled person moves from school to school, from school to the workplace, or from one workplace to another. This cycle can be broken if a disabled person is equipped with an appropriate accessor at the earliest feasible opportunity. Many recurring labor costs are eliminated. As well, costs to schools and employers are significantly decreased since it is usually only necessary for them to provide a Universal Access Port on each computer.

Individuals grow out of computers as situations and skills change. Children at elementary school will most likely use a small computer like the Apple. When they go on to high school they will be expected to use IBM PCs or Mackintoshes. When they continue on to university and work situations, they may be exposed to workstations and mainframes. All of these require different accessible interfaces under traditional approaches to accommodation. It is not unusual for disabled individuals to be using their fourth or fifth computer system and special interface by the time they reach a work situation. Every one of the computers they have used along the way represents a significant outlay for assessment, adaptations, and retraining on how to use the adaptations. In contrast, the Universal Access System makes it possible to equip disabled individuals with the most appropriate accessor at an early age, and for that accessor to remain with them throughout their education and into the work place.

The Universal Access System shares the cost of providing access among the different agencies in a way that more closely follows the way computer resources are provided for nondisabled people. Because accessors represent a more permanent solution than many of the current devices, rehabilitation agencies could invest more heavily in providing individuals with the most appropriate solution. A single accessor could meet the needs of a disabled individual for many years regardless of how his or her computing requirements change during the time. In other words, the job of providing an accessor could be done once, and done well, rather than provided as a series of stop-gap solutions. The provision of host computers for disabled students and employees could be handled by schools, universities and employers in much the same way as for nondisabled students and employees. In fact, the same computers can be shared by disabled and nondisabled users since the Universal Access Port has no impact on a computer when it is not being used by an accessor. The cost of a Universal Access Port is a relatively insignificant portion of the cost of a computer.

Independence

Universal access is not limited to computers. Any electronically controlled apparatus can be controlled by an accessor. Appliances, lights, telephones, entertainment equipment, elevators, ATMs, wheelchairs, and so on, can all be controlled by an accessor. This means that a disabled individual can use the same input and output strategies to control all of the equipment with which they normally interact. As a result, it will be much easier for a disabled person to become truly independent.

Design Rationale

The concept of a Universal Access System is basically simple: access functions are handled separately from applications. Among the reasons for adopting this approach are:

- Federal and State laws require all information processing equipment to be made accessible to disabled individuals. This includes: computers, appliances, environmental controllers, elevators, vending machines, automatic teller machines, and other electronically controlled devices
- As the complexity of computer operating systems increases, it becomes extremely difficult to incorporate special access modifications.
- As the complexity and size of applications programs get larger and more complex, it is becoming difficult to run access software and applications simultaneously.
- Some applications prevent programs from running at the same time.
- Different access software and hardware is required for each type of computer.
- Different access software and hardware is required for each type of disability.
- Functions related to providing access need to be separated from those related to running applications.
- Access functions should be portable to enable disabled individuals to use any computer in any location.
- The solution must be cost effective.
- Costs for implementing access must be minimized.
- Resources required to make individual workstations accessible need to be as small as possible. Resources are required to modify hardware and software, and to provide expert assistance with needs assessments, purchasing recommendations, provision of a suitable system, training of the disabled individual and his or her supporters, and maintenance.
- Access solutions must be durable. Changes in the applications used by a disabled person should not render existing access techniques or devices obsolete.
- Access operations should be consistent for any type of host computer or device

Acknowledgements

This project is being undertaken at California State University, Northridge. It is funded by a three-year federal grant from the Department of Education's Comprehensive Program Fund for the Improvement of Postsecondary Education (FIPSE).

Neil G. Scott
Office of Disabled Student Services, DVSS
California State University, Northridge
18111 Nordhoff Street
Northridge, CA 91330

Voice: (818) 885-2684
Fax: (818) 885-4929
E-mail: NSCOTT@VAX.CSUN.EDU

Training Therapists in Technology: Barriers and Solutions from the Third Year of the TechSpec Program

6.1

Roger O. Smith
Trace R&D Center
University of Wisconsin-Madison

Abstract

The demand for technology-trained practitioners has by far exceeded the supply of competent technologists. At the University of Wisconsin-Madison, a training program known as TechSpec was created to address this personnel training problem. The program is now moving through its third year. Generally, the graduates of this program have demonstrated continuing improvement in their technology knowledge and skills. In addition, technology training activities have included the production and dissemination of curricular materials. Several course guides and documents are currently available and have been distributed over the past year. More than 75 individuals and agencies have requested materials for review. While the TechSpec program has been an initial success, it has also revealed some key barriers to optimal technology education. Examination of the results of the TechSpec program has shown some limitations in its ability to address training deficits – limitations inherent in the scope of the program. There may be, however, alternatives for extending training programs and requirements to address the full need.

Background

For more than a decade, the assistive and rehabilitation technology field has acknowledged that it needs more and better methods for training practitioners to understand technology and to be competent in its application. Several years ago, a training program (TechSpec) was begun at the University of Wisconsin-Madison. Its objectives were 1) to improve the direct training of technology to professionals entering the rehabilitation and special education fields, and 2) to generate and disseminate training materials which could be incorporated into other developing technology training programs. The direct training initially targeted preservice occupational therapy students, with a later invitation to individuals from other related professions. The direct training component was divided into foundation and specialty tracks. The foundation track provided technology coursework as electives for any students. The specialty track, resembling a technology minor, required a specific set of core courses and electives.

Objective

The TechSpec program aimed to have 20-40 individuals enrolled in the foundation training activities, and to graduate 6-15 technology specialists per year. In addition, it was hoped that 10 occupational therapy professional training programs would consider using the technology curriculum materials developed in their own development of new courses or technology training activities. The work scope of the initial years of the project was to formulate the new courses and develop initial training materials. Later years were expected to revise materials, update the curriculum, and increase dissemination of information materials.

Methods/Approach

The TechSpec program contains six core courses:

1) Introduction to Assistive and Rehabilitation Technologies,
2) Design and Human Disability and Aging,
3) Adaptation and Construction of Equipment for Persons with Disabilities,
4) Technology Practicum,
5) Microcomputers and Software Applications for Occupational Therapists, and
6) Independent Study.

All of these courses have been established, and taught at least twice. In addition, a handful of elective courses from departments such as Human Factors Engineering, Computer Science, Physics, and Communication Disorders are available to students. The specialty track requires a 2-3 year enrollment, due to coordination of practicum scheduling with other professional fieldwork commitments.

Several specific strategies were implemented in the TechSpec program to accommodate projected problems which might arise. These strategies included interdisciplinary learning opportunities, innovative scheduling, and affiliation with several of the assistive and rehabilitation technology research and clinical programs on the university campus.

Results

TechSpec is now in its third year. A total of 147 students enrolled in the technology training courses during the first two years (102 occupational therapy undergraduates, 9 occupational therapy clinicians, 34 industrial engineering students, and 2 students from other related disciplines). In regard to the disseminable materials, more than 75 university curriculum programs and individuals have requested copies of the course guides and training materials.

The quality of the program is monitored, in part, through two tests: 1) a tally of the students' own subjective perception of their knowledge, and 2) an objective multiple-choice test. Both highlight the degree of success for this training program. Figure 1 depicts student scores on both subjective and objective tests at varying stages of their coursework.

Data are also compared between technology specialist students and the non-specialist students. These results are shown in Figure 2. Graduating seniors from the second year of the program demonstrate visible differences between the two groups. In this data set, the non-specialist group contains students who may have had some technology elective courses, but who are not enrolled in the specialty track. The technology specialists are those who have completed all of the core classroom courses.

Figure 1

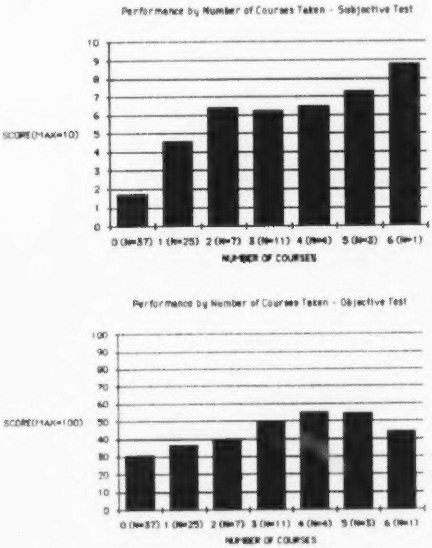
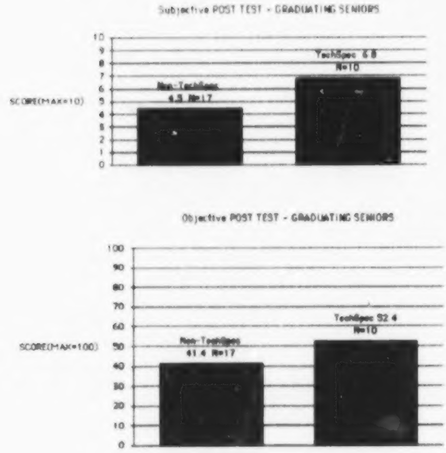


Figure 2



Discussion

The program has identified several problems which emerged over the first years of the program. These have stimulated suggestions about the field's current needs in technology training. Several of the needs and suggestions are briefly described here.

1) *Difficulty in scheduling fieldwork experiences:* Fieldwork experiences require a significant amount of time, and are usually difficult to schedule in and around required coursework for a pre-professional training program such as undergraduate occupational therapy.

2) *The need to have two levels of practicum experiences:* an elementary exposure, where the student observes a wide variety of technologies, as well as longer, more intensive, full-time specialty and hands-on fieldwork experience. The program's current requirements are for one practicum experience. This falls one step short of graduating therapists who are competent to immediately move into technology application in practice.

3) *Technology practitioners need to have two levels of academic preparation:* One is needed for students to develop an introductory technology knowledge base, which covers the full range of assistive and rehabilitation technologies being used. The second is to facilitate the development of practical skills. To do this, we have found that students require additional intensive training in a technology specialty area.

4) TechSpec is quite structured, and includes a variety of laboratory and lecture/demonstration courses. *The opportunity to discuss issues regarding the application of specific technologies, however, has not been incorporated.* More scholarly, seminar types of courses are felt to be missing.

5) *Adequate access to a variety of technology equipment* continues to tax even a campus which already had substantial resources available. Assistive and rehabilitation technologies require sufficient hands-on experiences for students. This has been difficult to coordinate with the research and clinical services using the technologies.

6) *The TechSpec program described is a 2-3 year program.* This provides time for students to integrate the technology they are learning, but the educational experiences at times seem shallow, as they spread over this extended time period. Thus, we have noticed that both a minimum level of intensity and a minimum time frame are required to optimize the quantity and quality of knowledge being conveyed and integrated.

These problems stimulate several ideas for solution.

- *Institutionalization of technology training at an undergraduate level* during basic rehabilitation, special education, and engineering professional programs. These programs should be oriented as technology minors, with the intent to lead students toward more specialty technology training later.
- *Availability of master's level technology training programs* for individuals who already have a

background in disabilities, rehabilitation and education.

- *Inclusion of two practicum experiences*; an observation-oriented introductory experience, and a more intense, lengthy practicum experience (6-9 months of full-time work).
- *Implementation of innovative access to technology equipment.* Ideas include video types of coursework, computer-assisted education systems, and training equipment loan systems.
- *Application of training over a 2-3 year program, but with an adequate intensity* of learning experiences throughout the time period. This is consistent with the graduate program model.
- *Linking of training program design to ongoing quality assurance* and certification efforts in the field.

Many of these points seem to indicate that more technology training is better. They also suggest that, as a field, we may be under-estimating the education required to produce competent technology practitioners. For the technology specialist, this has seemed to be true.

On the other hand, there does seem to be an important role for technology training programs, such as TechSpec. A solid introduction to technology, to acquaint students with potentials of technology, seems imperative. Rehabilitation therapists, special educators, engineers, and others need a basic understanding about the use of assistive and rehabilitation technology for persons with disabilities. Programs which do this provide the foundation for competent technology specialists who might attend master's degree technology programs or subsequent intensive technology training programs which then focus on specialty areas in technology.

Acknowledgements
Support for this project has been provided in part by Grant #H029F80083 from the Office of Special Education Programs, Personnel Preparation, U.S. Department of Education.

Roger O. Smith
Trace R&D Center
S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

6.2

DEVELOPMENT AND OPERATION OF A NATIONAL INFORMATION DISSEMINATION PROGRAM: ONE REC's EXPERIENCE

Jeanne O'Malley Teeter, M.B.A., Geoffrey B. Thrope
FES Information Center
Case Western Reserve University, Cleveland, Ohio

ABSTRACT

Each Rehabilitation Engineering Center (REC) sponsored by the National Institute on Disability and Rehabilitation Research (NIDRR) has responded to NIDRR's mandate for information dissemination with an individual approach. For most REC's, including ours, information dissemination was a new focus, requiring much in the way of start-up activity. The response of our REC was a full-fledged, national information center. Two years and one thousand requests later, we share the methodology of our approach and our experience to assist others involved in start-up information dissemination activities. We report our progress, focussing on the challenges of obtaining an optimal balance between development and service delivery activities.

BACKGROUND

In 1987, the NIDRR, recognizing the importance of information exchange in enhancing the development of assistive technology products and services, adopted a policy mandating that it's REC's sponsor formal information dissemination activities. Historically, the dissemination activities of most REC's was limited to technical presentations or publications such as formal papers and progress reports. While such dissemination activities were useful, NIDRR's primary concern was that specific information be made available to persons with disabilities in a useful format. As the stand-alone conduit for information dissemination activities at our REC, we established the FES Information Center in December of 1988. The mission of the FES Information Center is to serve as the national resource for information on Functional Electrical Stimulation (FES) technology, providing an objective representation of the status of FES and participating in the development and evaluation of FES products and services.

OBJECTIVE

In its 1987 Request for Proposals for Rehabilitation Engineering Centers, NIDRR provided general objectives for each REC. In our case, we were asked to accomplish three tasks during our five year funding cycle:

1) Develop and maintain a comprehensive information base on FES.
2) Disseminate the information in an accessible format to persons with disabilities, clinicians, Independent Living programs, counselors, third party payers, researchers, and manufacturers.
3) Coordinate the collation of research data among FES investigators, including related product information.

Our emphasis thus far has been to develop a strong base which can readily support the ongoing maintenance activities critical to an information dissemination program.

METHODS

I. Conceptual Approach

The NIDRR provided the REC's with specific details about "what" type of information was to be disseminated and to "whom". It was up to the REC's to determine "how" best to accomplish that. Of the numerous possible responses, we opted for a proactive approach which included the concept of a "national" information center, offering 1-800 telephone access and providing detailed coverage of international research activities in FES. To enhance the objectivity of our program, we positioned the Information Center as a stand-alone entity, distinct from the REC. To further enhance our credibility, we aligned ourselves with the Independent Living Center in our area- an organization with much expertise in information brokerage. This approach was particularly effective in our case because it gave us a high profile reputation for objectivity which was lacking in the field at the time. It also made us more accessible to outsiders with FES expertise aside from that of our own REC. Finally, the 1-800 service provided disabled consumers with immediate access to FES information which was previously available to them only via supermarket tabloids and TV talk shows.

II. Operational Approach

Operationally, the Information Center concept was challenging to implement. Although the objectives were clear, the "Catch-22's" of information dissemination became apparent to us early on. For example, how do you know what information is important to collect, unless you know what kind of information people will request? And how do you know what kind of information people will request, without giving them the opportunity to do so? Certainly, a thorough market research analysis would provide most of these answers, but would also be time consuming and costly. We adopted a parallel strategy whereby we address each objective simultaneously, fine-tuning our operations as we learn by experience. We felt comfortable with this strategy, primarily because competition was not a big factor in our marketplace.

Collection. The start-up collection strategies we used were conventional, yet effective. Our inclusion criteria has evolved along the way. We started with the personal libraries of our REC colleagues and added to that information collected via a mail survey to professionals in the field. We also utilized the Independent Living Center for gathering general resource information of interest to individuals with disabilities. Our ongoing collection activities include regular scanning of printed and on-line sources. Due to resource constraints, we deferred our original plan to expand our collection which called for citation analysis. Our current collection consists of over five thousand references, many of which are physically available on site.

Organization. Our parallel approach required that we have the ability, early on, to sufficiently catalog and organize incoming information. Therefore, we selected commercially available, yet customizable, database software for computer access. We contracted with an information scientist to set up our cataloguing and taxonomy schemes, making use of local focus groups to supply end user input into the process. Our reference materials are filed by identification number in color-coded folders. This system works well for access and retrieval.

Format. We primarily provide printed output to our clients in the form of bibliographies, reprints, and information packets. Audiotape versions of our in-house publications are available and we have a small library of videotapes. It is clear that most of the readily available information on FES is not in a format that is ideally suited to the lay consumer. We plan to study the particular needs of this lay consumer group in more detail through a separately funded project.

Access/Dissemination. Initially, access to our center was via our 1-800 telephone service or the U.S. mail. We have since added TDD, FAX, and an electronic bulletin board system (BBS). The dissemination methods are identical, with the addition of express mail provided at the client's expense. Although our original plans called for actual dissemination of our computer database, accomplishment of that objective has been postponed indefinitely. It is a task which requires resources not currently available to us.

Client Tracking. The only database that we developed from scratch was our Client Tracking System. We contracted with a computer programmer to implement a system that would allow us to record, classify, and respond to client inquiries. The system generates statistical reports of our request activities, useful for funding agencies, and is also used to maintain our mailing list. Due to resource constraints, the system was developed before we had much information and referral experience. At this time, it could be made even more useful with some enhancements.

DISCUSSION

There are many issues surrounding the development and operation of an information dissemination program; some are typical and others are program specific. One major issue for us has been juggling resource requirements in the face of fluctuating client demand. Demand peaks are typically not predictable, and are directly related to promotional activities at the national level. Such activities, though welcome, are often initiated by other organizations without our knowledge or advance notice. We have found that media coverage of FES activities can also be a double edged sword. While media coverage does promote awareness, it often results in public biases that are difficult to remove and take a significant amount of time to resolve. Another issue in the provision of information services is consumer involvement. Consumer input has been an invaluable resource to us in the development of our service offerings. It is available to us through our daily contact with consumers, through the Independent Living Center, and through consumer information exchange forums.

Performance evaluations are always an issue in information dissemination programs. We are convinced that the utility of performance information is always changing as a program grows and develops. In our case, we have found that at this stage, performance parameters such as volume of requests received and staff time required to respond are perhaps more important than such measures as turn-around time. Finally, determining how to ensure long-term financial support for an information dissemination program is an issue for every information dissemination program. To relieve the Information Center's reliance on grant related funds, we intend to explore corporate sponsorship of our activities and will attempt to further leverage our existing relationships with interested organizations.

ACKNOWLEDGEMENTS

This project is supported by the National Institute on Disability and Rehabilitation Research. The FES Information Center is affiliated with Services for Independent Living, Inc.. The authors acknowledge the assistance of Barbara Pausley, Ph.D. and Kevin Beck Software.

FES Information Center
10524 Euclid Avenue
Cleveland, OH 44106
1-800-666-2353

TECHNOLOGY TRAINING: RESOURCES FOR THE TRAINER

Susan E. Elting and Nancy L. Meidenbauer
Center for Special Education Technology
The Council for Exceptional Children
Reston, VA

ABSTRACT

As part of its technology training theme, the Center for Special Education Technology has developed several information products to assist trainers in planning and conducting training programs. It has also established a national trainer network to provide support for the isolated technology trainer.

BACKGROUND

The Center for Special Education Technology is a national information center funded by the U.S. Department of Education, Office of Special Education Programs. A major component of the Center's services is its indepth focus on identified themes in special education technology. Technology training is one of its current information themes.

Training was chosen as a theme because the need for information about training is great. The rapid increase in the number of devices and microcomputers has created a shortage of trained personnel. If technology is to continue to be successfully integrated into the curriculum, then careful attention needs to be paid to the training of classroom teachers, related service personnel, and early intervention specialists. Lack of sufficient technology training may, in fact, impede effective classroom use of technology.

DEVELOPMENT OF TRAINING RESOURCES

In June 1990, the Center conducted a National Forum for Technology Trainers as the kick off for the technology training theme. Forty-five expert trainers attended this invitational meeting to discuss issues and concerns regarding infusing technology in training programs. Several trainers presented models they use for organizing and implementing inservice and preservice training.

Specific training resources have been developed based on recommendations from individual trainers, advisory board deliberations, and planning committee input. To date, the Center has developed a series of publications which it hopes will assist trainers plan and conduct technology training programs.

It has also established a support network of trainers to foster the exchange of information among professional trainers. Information gathered at the National Forum meeting has been incorporated into the various training resources developed by the Center.

Publications

Videotapes, software, curriculum guides, and textbooks that might be used for special education technology training are listed in the Directory of Technology Training Materials. Materials encompass awareness topics, how to use specific hardware devices and software programs, applications of computer technology in the classroom, and assistive technology access to learning topics.

Two guides provide practical how-to information. The Trainer's Resource Guide: Program Planning Ideas includes a discussion of how to design a training program, descriptions of models of several inservice and preservice training programs, and frank first hand accounts of lessons learned from those who implemented the programs. There is also a summary of various published technology competencies.

The Trainer's Resource Guide: Training Materials Design Guidelines offers helpful hints for trainers wishing to design their own training materials. Systematic design and planning are stressed. Many guidelines are included with more publications referenced. Desktop publishing programs, presentation software, and CAI and IVD authoring software recommended by expert trainers are listed.

The Comprehensive Assistive Technology Curriculum Outline: A Functional Student-Centered Approach looks at technology use as it relates to the skills students need in school, to aid hearing, speaking, writing, and reading. This outline can be used by trainers to structure workshops or augment existing courses. Topics are organized in modules.

Training that commercial producers provide is examined in the Fall 1990 issue of the Center's The Marketplace: Publishers/

Producers An Important Link to Technology Training. It includes examples of how commercial producers are providing training and technical assistance to their clients.

The Center has compiled a Resource Inventory of University-based Technology Training Programs. This listing summarizes the programs by state. Codes indicate the type of degree granting special education program for each institution, as well as how training is presented (e.g., course, independent study) and topics of instruction (e.g., assistive technology, instructional uses of computers).

Networks

The Center has newly established a trainer network for university-based trainers and is attempting to create another network for inservice trainers. Members of the university-based trainer network tend to be isolated practitioners, infusing technology within existing courses at their respective institutions. Members receive new information products from the Center. They also have access to the other trainers in the network for mutual support and encouragement. There are plans to bring network members together at national and regional meetings and via audio conferences.

SUMMARY

Technology training will remain a critical need for professionals working with special education students. It is only by acknowledging this need that resources can be amassed to address this need.

ACKNOWLEDGEMENTS

This project is funded by the Office of Special Education Programs, U.S. Department of Education under Contract No. 300-87-0115 and operated by Council for Exceptional Children. For more information, contact The Center for Special Education Technology, CEC, 1920 Association Drive, Reston, VA 22091 or call 800/873-8255.

6.4

MSDOS-ABLDATA: An MS-DOS and screen reader compatible program for retrieving information from ABLEDATA

Alan VanBiervliet & Gail L. Cox
Center for Research on Teaching and Learning
University of Arkansas at Little Rock
Little Rock, AR

Abstract

MSDOS-ABLEDATA was developed in order to provide easy access to the public domain ABLEDATA database for persons who use computers with the MS-DOS operating system. MSDOS-ABLEDATA was designed to be compatible with screen reading software which will enable the program to be used by blind and sighted individuals. PC-ABLEDATA uses a simple menu structure to provide easy access to the desired data. The program incorporates most of the features of Hyper-ABLEDATA, including modified Boolean searching, saving and printing records, recording personal notes, and automatic letter generation.

Background

P.L. 100-407, the *Technology -Related Assistance for Individuals With Disabilities Act of 1988*, has resulted in an increased awareness of the importance of the dissemination of accurate information about assistive technology to consumers and professionals. One solution to meeting this need has been the creation of dozens of assistive technology information services throughout the U.S. One of the most popular components of these services is the Hyper-ABLEDATA system. The Hyper-ABLEDATA system contains the entire ABLEDATA rehabilitation and assistive technology database in a user-friendly format (Smith, Vanderheiden, Berliss, and Angelo, 1989). Valuable features of a distributed database like Hyper-ABLEDATA are low cost, ease of use, and wide availability.

Problem

Hyper-ABLEDATA version 2.0 includes voice access capabilities and an excellent built-in help and training system. Currently, it is compatible only with the Macintosh computer which presents some access problems for persons who are visually impaired and experienced with the MS-DOS system and screen reading programs. The OutSpoken software program combined with the Mac's built in screen enlarging capabilities (i.e., CloseView) greatly improves access to the Mac's graphic interface. However, a wide variety of barriers still exist, for example, OutSpoken currently does not work with HyperCard files or stacks.

Design

MSDOS-ABLEDATA is designed to operate any MS-DOS-based computer with at least 640k of RAM. MSDOS-ABLEDATA uses the approach of a "current list of records". The operator can create a new list that is based on the type of product, product name, or manufacturer's name. The operator can also save any list that he/she created and edit or print the list at a later time. MSDOS-ABLEDATA uses a layered menu structure to provide easy access to the desired information. Four basic menus are used to create and manipulate each list, these are: List Creation/Selection, Product Type Outline, List Management, and Special. Menu items can be selected via cursor keys or by typing the first letter of the desired menu item. The menu can be terminated by selecting the EXIT selection or by pressing the "ESCAPE" key. All menus in the program operate in a similar manner.

When searching for a type of product, a screen appears that provides an outline of general product types. The operator can select one of these categories either by cursor or by entering enough characters to make the selection unique. The screen will clear and the selected category will appear at the top of the screen and all applicable subcategories will be presented as before. This process continues until either the operator presses "F2" or the end of the outline is reached. When an outline category contains sublevels, it will be followed with a "+" character. When this process is completed, the List Management will be presented.

When searching for a manufacturer or a particular product by name, the operator is prompted to enter the desired name. Partial or whole names are acceptable entries. The selected record will then be displayed on the screen.

The List Management menu provides the operator with the number of records that have been selected and provides options to further restrict the current list. Three basic Boolean operations are available to narrow the list, these are "and", "or", and "not". The "and" option allows the list to be narrowed by eliminating records that do not contain both text strings listed in the arguments. The "or" option eliminates records from the list that do not contain at least one of the text strings listed in the arguments. The "not" option will eliminate records from the current list that do contain the text string listed in the argument. The operator can also eliminate products from the current list that have been discontinued by the manufacturer. The operator also has the option to save the current list for further reference or printing.

The Special menu provides the options for notes, printing formatted letters, and saving the current list. Personnel notes or comments can be attached to any record. Examples of notes could include a listing of local representatives or vendors for a particular product. A custom letter can be automatically printed to the manufacturer or the inquirer. The current list can also be saved to disk in a text file, perhaps for printing at a later time, or an unformated file can saved for use with a Braille translation program.

Evaluation

At periodic points throughout the development of MSDOS-ABLEDATA, experienced computer users who use screen reading programs to access digital information were consulted regarding the operation and features of the program. These hands-on tests led to a number of design improvements. MSDOS-ABLEDATA is currently undergoing a systematic evaluation in preparation for multi-site field testing. An important test that is underway is to comparing the time identical searches take using Hyper-ABLEDATA and MSDOS-ABLEDATA. These tests are also comparing the lists of products found using the same search criteria.

Acknowledgement

This work was funded by the National Institute of Disability and Rehabilitation Research (NIDRR), U.S.Dept. of Education, Grant # H224A90020-91. The contents of this publication do not necessarily reflect the views of NIDRR, USDE, and do not imply endorsement by the U.S. government.

References

1. Smith, R.O., Vanderheiden, G.C., Berliss, J.and Angelo, J. Creating and testing an effective design for a desktop version of ABLEDATA. Proceedings of the 12th Annual Conference on Rehabilitation Technology, New Orleans, 1989.

Alan VanBiervliet
Center for Research on Teaching and Learning
University of Arkansas at Little Rock
2801 South University
Little Rock, AR 72204

7.1

UTILIZING TECHNOLOGY IN THE VOCATIONAL REHABILITATION PROCESS

Anthony J. Langton
Center For Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department

ABSTRACT

Use of assistive technology resources and services within vocational rehabilitation programs was analyzed. A study group consisting of rehabilitation case management staff and technology specialists identified key decision points and service activities to determine where technology services should be utilized. Nine TECH POINTs were identified and are briefly explained. Additional considerations for further work are discussed.

BACKGROUND

Determining vocational potential remains one of the most challenging and important aspects of rehabilitation services. Vocational rehabilitation counselors are expected to make eligibility decisions and determine if an individual has a "reasonable expectation" to benefit from rehabilitation services.

Rehabilitation engineering technology must play a key role in this process. Technology resources can be beneficial to a large number of rehabilitation clients, particularly those individuals with severe disabilities. Although widely acknowledged as important, little in the way of a systematic strategy on how to integrate technology into the rehabilitation services process has been presented.

Mandates for use of technology

The 1986 Amendments to the Rehabilitation Act, Public Law 99-506, for the first time specifically mentioned "rehabilitation engineering" as a service which should be made available. With passage of Public Law 100-407, The Technology-Related Assistance for Individuals with Disabilities Act of 1988, the federal government echoed its recognition that all people with disabilities can benefit from technology (American Rehabilitation, 1990).

Earlier, in 1973, passage of the Rehabilitation Act Amendments directed vocational rehabilitation programs to initiate programming designed to focus services on the needs of those individuals with severe disabilities. The Rehabilitation Services Administration (RSA) has continued to make it clear that rehabilitation engineering technology is an essential resource needed for the severely disabled and other rehabilitation clients (RSA, 1990).

Vocational Rehabilitation Process

Services delivered through vocational rehabilitation agencies follow standardized case management procedures. Comprehensive rehabilitation services are comprised of a large number of sequential activities which are individualized to meet the needs of specific clients. Figure1 illustrates the overall vocational rehabilitation process. Technology and technology related services are, or should be, an important part of many of these activities.

PROBLEM

The use of technology resources within the rehabilitation process remains limited. Technology and technology related services have yet to be clearly defined by many vocational rehabilitation agencies. Often the technology services which are provided are not effectively integrated into regular case management activities. When utilized, rehabilitation engineering services are most commonly considered during placement activities in the latter stages of the rehabilitation process (IRI, 1986).

Case management staff often do not have a sufficient understanding of when or how technology should be utilized. As a result technology resources are often not considered. Individuals who may have vocational potential could be determined to lack eligibility because the capability of technology to reduce handicapping conditions and increase performance is not considered.

METHODOLOGY

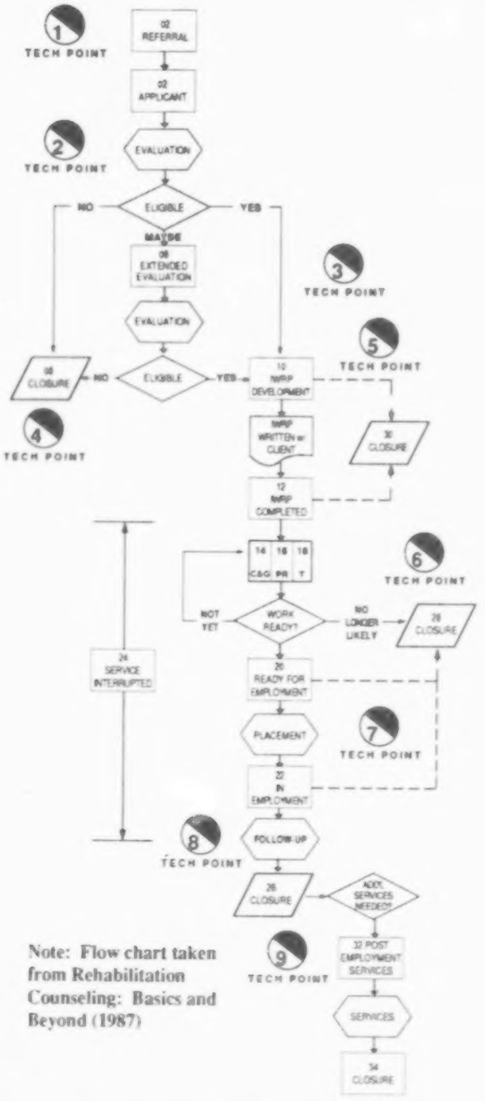
Although vocational rehabilitation programs differ in their resources and specific policies, they operate within the same guidelines and generally follow similar procedures. This project looked at the overall rehabilitation process to develop a method(s) to better integrate technology services. A study group of rehabilitation case management staff and technology specialists met to determine when and where technology resources should be utilized. Findings from this group were then compared with VR case status activities.

RESULTS

Nine separate places in the rehabilitation process were identified where consideration of the use of technology or technology related services should take place. These points each represent decision points where technology resources/services could be recommended or phases of services where technology resources could be appropriate.

TECH POINTS

The TECH POINTS are briefly outlined indicating questions or considerations that should be made regarding the possible application of technology services. Reference is given to VR case status numbers, such as (02), where appropriate. Figure 1 also shows locations of the TECH POINTS within the overall rehabilitation process.


① TECH POINT
02 REFERRAL
02 APPLICANT
② TECH POINT
EVALUATION
NO
ELIGIBLE
YES
MAYBE
06 EXTENDED EVALUATION
③ TECH POINT
EVALUATION
08 CLOSURE
NO
ELIGIBLE
YES
10 IWRP DEVELOPMENT
⑤ TECH POINT
④ TECH POINT
IWRP WRITTEN w/ CLIENT
30 CLOSURE
12 IWRP COMPLETED
14 CAG
16 PR
18 T
⑥ TECH POINT
NOT YET
WORK READY?
NO LONGER LIKELY
28 CLOSURE
24 SERVICE INTERRUPTED
20 READY FOR EMPLOYMENT
PLACEMENT
⑦ TECH POINT
22 IN EMPLOYMENT
FOLLOW-UP
⑧ TECH POINT
26 CLOSURE
ADD'L SERVICES NEEDED?
⑨ TECH POINT
32 POST EMPLOYMENT SERVICES
SERVICES
34 CLOSURE

Note: Flow chart taken from Rehabilitation Counseling: Basics and Beyond (1987)

Figure 1
Vocational Rehabilitation Case Management Flow Chart

① TECH POINT

Initial Referral (02): During preliminary contact with individuals seeking rehabilitation services counselors should question whether technology resources could be of benefit. This should include communication, mobility, environmental control, work station adaptations or any other aspect of assistive technology. *Individuals should not be denied services or referred elsewhere without a basic technology consultation.* This may require services of a rehabilitation engineer or other technology specialist.

② TECH POINT

Evaluation phase : Can this individual be evaluated with standard assessment procedures? Will any accommodations be needed to thoroughly assess the individuals capabilities and effectively determine vocational potential? Assistive aids and devices for communication, mobility, manipulation, writing and other task performance should be available as part of the evaluation. Individuals needing in depth technology assessments should be referred for extended evaluation.

③ TECH POINT

Extended Evaluation (06): Resources of a technology team should be available to provide specialized technology assessments. Technical assistance from rehabilitation engineers or other technology specialists should be available as needed. Determination of "*reasonable expectation*" should include consideration of technology resources.

④ TECH POINT

Closed Non–feasible (08): Prior to being determined ineligible, the functional problems encountered and the utilization made of assistive technology resources and services should be indicated. *Consultation with the Technology Team should be done prior to closure.* Information from this consultation should be sent with referral to alternative resources or for considerations for independent living services.

⑤ TECH POINT

Plan Development (10): The Individually Written Rehabilitation Plan (IWRP) should *identify assistive technology and technology related services necessary to achieve vocational goals.* Documentation of specific types of services needed and equipment options for consideration are necessary.

⑥ TECH POINT

Planned Services (14,16,18): Technology resources or services needed to complete training or physical restoration should be provided. Accommodations are likely to be necessary for school activities or independent living issues. Access to a rehabilitation engineer or other Technology Team members should be available for problem solving.

⑦ TECH POINT

Placement Phase (20): What technology needs are there for placement? *Accommodations needed are likely to include work site modification, independent living assistance, custom equipment development, transportation/mobility, etc.* Problem solving as well as fabrication resources would need to be available. Access to the Technology Team or individual technology specialists would be required.

⑧ TECH POINT

Follow–up (22): Follow–up should be provided on the performance of specific assistive aids/devices or work site accommodations made. During trial placement periods, problems (if any) should be identified and determination of need for technology support resources made. Site visit by technology specialist may be necessary.

⑨ TECH POINT

Post Employment Services (32): Support should be provided for maintenance or repair of aids or devices. Arrangement for replacement of equipment or provision of technical assistance should be available.

BEST COPY AVAILABLE

CONCLUSION

The integration of TECH POINTS within the case management process should enable vocational rehabilitation agencies to better identify when they should use technology services and more accurately determine what technology services their clients need. Development of specific questions and procedures at each point will depend on resources available within particular vocational rehabilitation programs. Tracking of technology resource/service activity at each point will enable programs to more effectively evaluate its benefits and cost-effectiveness.

The following information summarizes additional considerations which should be taken into account when implementing the "Tech Points" approach:

Key Decision Points

In all rehabilitation programs the delivery of rehabilitation services relies heavily on the capability of the vocational rehabilitation counselor to work with the client to identify feasible goals and to develop a workable plan to achieve these goals. Critical decisions during the *evaluation, individual written plan development and work readiness phases of the rehabilitation process* were identified as primary points where technology resources should be emphasized.

Continuous Process

The problem solving and support available from technology services should remain available throughout the rehabilitation process. The identification of specific "check points" was developed as a way to assist case management staff in monitoring the utilization of technology. *It is important that technology services and resources be considered anytime during the rehabilitation process.*

Population Considerations

Decisions on the use of technology obviously must depend primarily on the specific needs of the individual. Depending on the nature of a person's disability and functional limitations, the need and scheduling of technology intervention will vary. While not as obvious, utilization of assistive technology with non-physically disabled populations may still be necessary depending on functional limitations.

Role of Staff

Determining whether technology resources should be utilized remains primarily the responsibility of the vocational rehabilitation counselor. *As case manager, the rehabilitation counselor needs to have, 1) a basic understanding of assistive technology and 2) access to technology support staff.* Utilization of rehabilitation engineers or other technology specialists as part of a "technology team" should be available to assist at these various points.

Time Frames

Availability of technology support staff and turn around time are important variables in the successful integration of technology services. Response time to requests should fall within the agency guidelines for length of time which individual clients normally remain in particular statuses. Utilization of extended service options may be necessary.

Need for Training

Developing a general awareness of assistive technology for all case management is important for the TECH POINT approach to be successful. Specific training materials describing questions to be asked and resources available will also be necessary.

ACKNOWLEDGEMENTS

The Center for Rehabilitation Technology Services is part of the South Carolina Vocational Rehabilitation Department and is a rehabilitation engineering center supported by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Washington, D.C. Study group members included: Ronald Fry, Stephen Thomas, Judy Hughes, Lucerne Melton, Kerry Mandeville, Greg McGrew, Marcia Nunnally, Lydia Gaster. Illustration done by Valerie Augustine.

REFERENCES

Corthell, D.W. Rehabilitation Technologies: Thirteenth Institute on Rehabilitation Issues, Research and Training Center, UW-Stout, Menomonie, Wi. 1986.

Langton, A.J. "Delivering Assistive Technology Services: Challenges and Realities", Proceedings from the Southeast Regional Symposium on Assistive Technology, Center for Rehabilitation Technology Services, 1990.

Parette, H.P. and VanBiervliet, A. "Physical Disability and Technology Needs", American Rehabilitation, Spring 1990.

Rehabilitation Services Administration, "Rehabilitation Engineering Technology" Technical Assistance Circular, RSA-TAC-91-01, Washington DC. 1990.

Parker, R. M., Editor. Rehabilitation Counseling: Basics and Beyond, Pro-ed Publisher 1987.

S.C. Vocational Rehabilitation Department. Case Service Policy Manual, 1990.

Anthony J. Langton
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department
1410-C Boston Ave.
P.O. Box 15
W. Columbia, SC 29171-0015

COOPERATIVE SERVICE DELIVERY: A COST-EFFECTIVE STRATEGY

Lydia S. Gaster , Anthony J. Langton and Lawrence H. Trachtman
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department
West Columbia, South Carolina

ABSTRACT

Delivering assistive technology services requires an extensive investment of staff and equipment on the part of individual agencies and programs. The Center for Rehabilitation Technology Services has designed a service delivery model to reduce the costs incurred by individual programs. Cooperative agreements between a host and a number of affiliate programs were used to establish the base for a comprehensive assistive technology clinic. Projected cost comparisons indicate this approach will reduce costs to individual programs by as much as two-thirds or more. Additional incentives for participating include staff training opportunities, access to a technology team and the opportunity to utilize assistive aids and devices.

INTRODUCTION

The field of assistive technology constantly struggles to overcome reimbursement problems related to services and equipment costs. The high cost of experienced clinicians and engineers coupled with assistive technology's labor-intensive nature prevents many agencies from providing such programs. An assistive technology cooperative provides a potential solution to this dilemma. Such an organization may consist of several area agencies and health care facilities sharing the expense of assistive technology services. By joining a cooperative, a facility can access assistive technology services for less than a third of the cost of starting and supporting a program on its own.

The Greenville Assistive Technology Cooperative (GATC) located in Greenville, South Carolina, provides an example of such a cooperative. The cooperative consists of several health care facilities, the local school system, the Easter Seal Society, Vocational Rehabilitation, local medical equipment dealers and the Department of Mental Retardation.

BACKGROUND

The Greenville Assistive Technology Cooperative was organized as a project to study alternative service delivery systems. South Carolina's Piedmont area was chosen as the test site because it possesses the state's highest concentration of assistive technology expertise. Many of the "grass roots efforts" to provide assistive technology services started in this region. The Cooperative will be replicated in South Carolina's remaining three regions: Midlands (Columbia area), Pee Dee (Florence area) and Low Country (Charleston area). As seen in Figure 1., these cooperatives will form the hub of each region's service delivery activity and together provide statewide coverage.

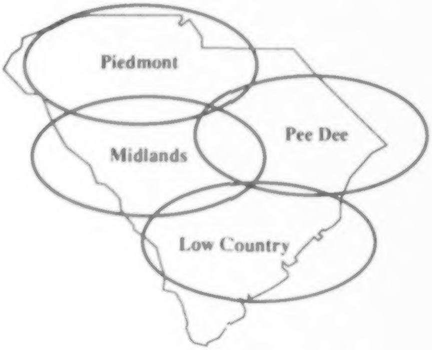


Figure 1. Regional Service Areas

Prior to the Center for Rehabilitation Technology Services' efforts, little had occurred to develop and expand assistive technology services. Service provision in the region has been fragmented at best. Programming within individual agencies was frequently delivered by staff with limited specialized training in assistive technology. Those programs with staff who had specialization in areas of assistive technology were limited in most cases by available resources.

The Cooperative's evolutionary process has taken many turns. Extensive ground work was required to "sell" the concept to the various supporting agencies. Differences in missions and unique problems produced many issues requiring individual attention. It was vital to understand each agency's financial structure and mandate so that it may "profit" by being affiliated with the Cooperative. For example, some agencies can bill third-party payors for the services they buy through the Cooperative; others benefit because they pay less for assistive technology services through the Cooperative.

Host/Affiliate Relationship

A simple host and affiliate relationship was proposed to interested programs and agencies. The "host" facility provides space and operational support to the technology clinic while contributing a limited amount of staff time as well. "Affiliate" members contribute staff time and assistive technology equipment. Involvement as either host or affiliate members entitles access to training resources and equipment demonstration and try-out.

Local Ownership/Control

A fundamental concept emphasized from the onset was the importance of gaining a commitment from local service providers. In order to foster this, a free standing advisory board comprised of representatives from each participating program and agency was implemented with authority to monitor the technology clinic operation. Initiation of non-profit status was also begun to enable the Cooperative to remain flexible and possibly seek outside funding from a local foundation or service club.

Coordinator Position

Implementation of the technology clinic portion of the Cooperative required immediate availability of a "coordinator" to attend to specific details such as scheduling, locating funding, marketing, and team coordination. While it would have been desirable for this individual to have their own technical expertise it was felt that it was more important that this person be knowledgeable of overall service delivery and funding awareness. The technical skills necessary for clinic operation could be provided by staff from host or affiliate members.

METHODOLOGY

Several steps led to the Cooperative's development. The first step was to create an advisory board consisting of individuals from various community agencies. This was crucial as the cooperative's success hinged on a commitment from administrative personnel within the member agencies. An integral part of the advisory group included direct consumer representation to increase awareness of consumer needs. Next, the Cooperative's basic structure emerged through numerous advisory board meetings. A "host" facility was sought as the site for the clinical activities. Once the host facility was established other programs and agencies became participating "affiliates." Much of the financial support for start-up activities came as in-kind support from the host and affiliate agencies. The Center for Rehabilitation Technology Services (CRTS) served as the catalyst for the development of the project.

Other steps crucial to the Cooperative's organization included written cooperative agreements, formal development of a governing board, obtaining non-profit status, the development of revenue-producing activities and marketing and outreach activities.

Participating Members

Delivering comprehensive assistive technology services required access to staff with varying areas of expertise and specialized equipment. In identifying prospective members, agencies and programs with resources benefiting the cooperative as a whole were invited. Figure 2. shows the member types the cooperative sought.

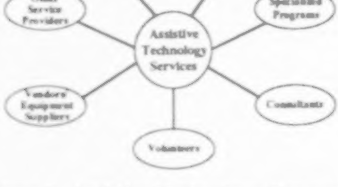


Figure 2. Assistive Technology Cooperative Members

Cooperative Agreements

Developing specific cooperative agreements for each participating program was an important step. Representatives from host and affiliate programs provided extensive input into the development of these agreements. Despite initial expressions of support from programs and agencies, considerable questions surfaced when each participant was faced with a written agreement requiring staff and resource commitment. It became necessary to set general participation guidelines and to "tailor" these agreements to address individualized needs. This flexibility and need to "negotiate" proved critical to initiating services.

Service Parameters

Selection of what services to offer was influenced primarily by the anticipated ease of reimbursement. Services included prescriptive and evaluative activities in the areas of seating/positioning, environmental control, augmentative communication and computer access. It was immediately realized that capability for fabrication, development of custom devices, and providing the full range of services would eventually need to be included. Expansion will be attempted once a stable service base is in place.

RESULTS

Cooperative activities were initiated in January 1990. Participants in the Cooperative included:

Host	Affiliates
Greenville General Hospital	•Center for Developmental Pediatrics
(Greenville Hospital System)	•Greenville County Public Schools
	•Roger C. Peace Rehabilition Hospital
	•SC Vocational Rehabilition
	•American Rehabilitation (DME)
	•Carolina Homecare (DME)
	•Department of Mental Retardation
	•Center for Rehabilitation
	•Technology Services
	•Shriner's Hospital
	•Easter Seals Society

Projected Cost Comparisons

Preliminary cost analysis underscores the potential of the cooperative to be a cost effective model for delivering assistive technology services. Significant personnel (labor) and facility (rent) savings can be realized through the advantage of a cooperative arrangement. **Figure 3.** shows the projected monthly cost savings of the cooperative model over a traditional service delivery model.

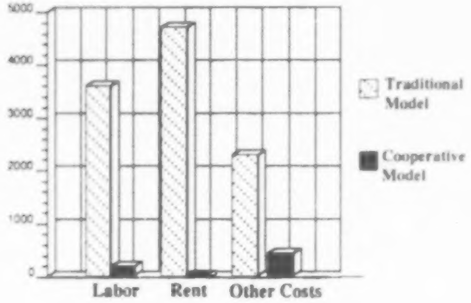


Figure 3. Projected Cost Comparisions

Figure 4. shows the comparison of contributed value between the host and the affiliates. The host portion of the graph represents office space and staff contribution. The affiliate portion indicates staff and equipment contributions.

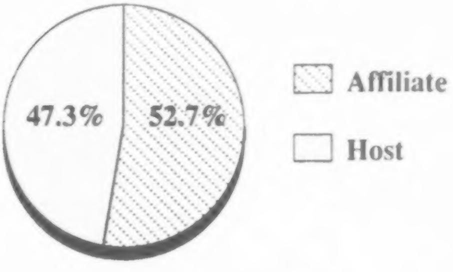


Figure 4. Affiliates and Hosts

DISCUSSION

A cooperative model is proposed as a way to provide financially feasible, low-volume services requiring a high degree of expertise. A cooperative can work as long as the benefits outweigh the costs of affiliation. Any staff time donated by affiliates must be counter-balanced by some amount of financial recovery or staff training. Cooperative affiliation must also be perceived as a staff recruitment tool and should produce positive public relations. Participation should also offer member agencies access to skilled professionals difficult to recruit such as rehabilitation engineers and other technology specialists. When the proper balance is struck, a cooperative may be one solution to the financial problems plaguing most service delivery programs.

One important factor that must exist in the early stages of a cooperative is the availability of a "facilitator" to pull the various programs and agencies together. This type of delivery approach depends on a significant contribution of time on the part of staff from a key program, in this case the Center for Rehabilitation Technology Services, for the concept to be "sold" to interested groups. As noted with the Hasbro-Alabama Positioning Network (1989), it is imperative that this leadership responsibility be provided in order for implementation to be successful.

CONCLUSIONS

It is too early to draw any firm conclusions or to predict whether this approach will be successful in the long run. Preliminary indications reveal that the concept, although simplistic and new to assistive technology, offers sufficient merit for consideration as an alternative delivery model.

ACKNOWLEDGMENTS

The Center for Rehabilitation Technology Services, part of the South Carolina Vocational Rehabilitation Department, is a rehabilitation engineering center supported by the National Institute on Disability and Rehabilitation Research.

BIBLIOGRAPHY

Willkomm, T. The Application of Rural Rehabilitation Technologies: A Community Based Approach. RESNA, Proceedings of the Twelfth Annual Conference on Rehabilitation Technology, New Orleans, LA, p. 49–50, 1989.

Letechipia, J. E. Procedure to Implement a Rehabilitation Technology Service Delivery Program. RESNA, Proceedings of the Twelfth Annual Conference on Rehabilitation Technology, New Orleans, LA, p. 212–213, 1989.

Brockman, R. T. Public and Private Resources: Discovering an Open Ear to Implementing Services. RESNA, Proceedings of the Twelfth Annual Conference on Rehabilitation Technology, New Orleans, LA, p. 329–330, 1989.

Heiner, D. E. Collaborative Consultation: A Model for the Provision of Enabling Technology Services. Proceedings of the 13th Annual Conference, Washington, DC, p. 249–250.

Drews, J. et.al. The Hasbro-Alabama Positioning Network, RESNA, Proceedings of the Thirteenth Annual Conference, Washington, DC, p. 242-243 1989.

Lydia S. Gaster
Anthony J. Langton
Lawrence Trachtman
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department
1410–C Boston Avenue, P.O. Box 15
West Columbia, South Carolina 29171–0015

7.3

Development of a Model Rehabilitation Engineering Program

Rory Cooper, Al Cook, and Tom Grey
Rehabilitation Engineering Program and Assistive Device Center
Department of Electrical and Electronic Engineering
California State University, Sacramento

ABSTRACT

For years innovative health care providers and persons with disabilities have selected, modified, and developed technological devices to meet the needs of persons with disabilities. These people are still invaluable to the rehabilitation process; however with the increasing complexity of technology and the potential benefit to persons with disabilities there is an increasing need for formal training of rehabilitation engineers.

Background

The enactment of two Federal Laws (PL 99-506 and PL 100-407 in 1988) as amendments to the Rehabilitation Act of 1973 show that persons with disabilities are drastically in need of assistive technologies and are not able to obtain them. Under these laws each state vocational rehabilitation plan must include the provision for rehabilitation engineering services. This requirement should create a greater demand for rehabilitation engineers.

Statement of the Problem

A recent State of California Report (California Application, 1989) estimates that at least 809,729 persons in California are in need of assistive technologies, most of whom have needs which are unmet or are met inadequately.

Approach

We are developing a curriculum for a rehabilitation engineering concentration within our biomedical engineering program which will lead to an MS (Biomedical Engineering) degree with a Certificate in Rehabilitation Engineering. The curriculum includes basic coursework in biomedical engineering, formal courses in rehabilitation engineering (including laboratories), research experience, clinical experience, and fieldwork. The curriculum provides a well rounded program in rehabilitation engineering with some freedom to specialize in one of several specific areas of interest (e.g., wheeled mobility, seating and positioning, augmentative communication, computer access, or robotics). This program includes a formal clinical experience in rehabilitation engineering involving a wide variety of clinical and programmatic environments.

Stipends are awarded to five (5) students each year from project funds. In addition, students are supported as interns in the Assistive Device Center, as research assistants, and as teaching assistants.

Course Work

Students receive a balanced education in biomedical engineering by taking courses in Bioengineering Analysis, Bioelectric Phenomena, Homeostatic Transport Systems, Engineering Applied to Body Materials and Fluids, and Human Performance and Disability. Students in the rehabilitation engineering program take courses in neuroscience, and systematic physiology. An assistive technolgy seminar addresses major issues in rehabilitation engineering. The students also perform research under the guidance of one of the faculty members and prepare a thesis for submission to the faculty. To receive the rehabilitation engineering certificate, in addition to the M.S.(BME) degree, the students must complete an internal and external fieldwork in rehabilitation engineering, satisfactorily complete a course in rehabilitatin engineering design, and successfully pass a comprehensive examination on rehabilitation engineering principles and practices.

The rehabilitation engineering courses provide broad coverage of rehabilitation engineering. Students are introduced to assistive technologies, assessment for prescription and provision of appropriate devices. They also become familiar with human performance engineering, the nature, types and effects of disabilities, and the role of assistive technology in ameliorating disability in computer access, communication, environmental control and sensory loss. The aspects of designing, developing and manufacturing assistive devices and technology for mobility, transportation, and manipulation (including robotics) are presented in rehabilitation engineering design. Social, political, legal, and present research areas are discussed in the assistive technolgy seminar. Experts in rehabilitation and public policy regularly make presentations to the students and faculty in the seminar

Assistive Device Center (ADC) Field Work

A major shortcomming in rehabilitation engineering training is the absence of a formal clinical fieldwork experience. All of the students in the rehabilitation engineering program participate in a one semester fieldwork rotation in the ADC. During the student's internship at the ADC he/she spends time working in each of the major service areas: Wheeled mobility, seating and positioning, augmentative communication, computer access. Weekly meetings are held to monitor progress and answer questions. All students are required to attend regular Client Services meetings with the staff of the ADC, which includes rehabilitation engineers, occupational therapists and speech and language pathologists. This helps to foster a transdisciplinary approach.

After a student has had some experience in the ADC, he/she is assigned to one or two clients. Each student is responsible for ordering the appropriate assistive technolgy for their clients based on team recommendations. The student then delivers the assistive technology, makes any adaptions, and trains the client and support team in its use.

External Field Work

Each student in the rehabilitation engineering program participates in a summer internship program in a hospital, rehabilitation center, or a community based center for assistive technology. Students are responsible for observing the assessment of clients and the evaluation of appropriate assistive technologies, and they are exposed to the administration of rehabilitation engineering services in each setting. Students rotate through the various offices of the agency, learning the responsibilities of each of the offices first-hand. Students again experience a team approach to client assessment and rehabilitation engineering services.

Rehabilitation Engineering Field Placement Training Manual

In order to formalize the fieldwork training a Fieldwork Training Manual is being developed. The manual will consist of seven major sections: (1) Procedures used in rehabilitation engineering services, (2) Observation and interview skills, (3) Assessment and evaluation skills, (4) Recommendation and evaluation of technology, (5) Implementation of appropriate assistive technolgy, (6) Training of clients and other rehabilitation professionals, and (7) Follow-up.

Faculty Guided Student Research

Each student is required to participate in a faculty sponsored state-of-the-art research project in some area of rehabilitation engineering. The student is expected to make an original contribution to the field of rehabilitation engineering, and to learn basic research methods. Student research is supervised by faculty in the biomedical engineering program.

BEST COPY AVAILABLE

Implications

The success of this program will yield the following:

1. A model program for the training of rehabilitation engineers which provides the necessary theory, clinical skills and research/development experience for successful practice in rehabilitation engineering.

2. A model structured and systematic fieldwork experience in rehabilitation engineering leading to the development of the prerequisites for clinical practice in rehabilitation engineering.

3. A model research environment which will foster research and development skills in rehabilitation engineering graduates and provide the basis for future contributions to this field.

Discussion

Our goal is to develop a rehabilitation engineering program that will produce effective rehabilitation engineers. To this end, we require students to learn a number of skills, and we expose them in a formal manner to a variety of rehabilitation engineering settings. We teach students the multidisiplinary nature of rehabilitation engineering, and the importance of working within a team. The program is in development; however, we are confident of its eminent success.

Acknowledgements

This program is partially supported by Rehabilitation Services Administration, U.S. Department of Education under Award No. H129E00005, and the California State University, Sacramento. Fred Baldini, Colette Coleman, Sue Hussey, Miriam LeGare, Rick Robertson, Sheridan Whinnery, and Sheila Wolfe are responsible for major portions of this program.

References

California Application (1989). Application for a grant pursuant to the technology-related assistance act: PL 100-407. "A statewide program to make assistive technolgy available to individuals with disabilities". State of California: Department of Rehabilitation.

Rory Cooper
Coordinator
Rehabilitation Engineering Program
Biomedical Engineering
California State University
Sacramento, California 95819-6019

A COMPREHENSIVE REHABILITATION TECHNOLOGY SERVICE DELIVERY MODEL UTILIZING SPEECH RECOGNITION TECHNOLOGY

7.4

David M. Horowitz
Marilyn Lash
Rehabilitation Engineering Program
Department of Rehabilitation Medicine
Tufts University School of Medicine

ABSTRACT

A recently initiated comprehensive rehabilitation technology service delivery model is presented. The intent of the model is to increase the availability of reliable and durable assistive technology that addresses the complex technology-related needs of individuals with disabilities. The model brings to bear important technological and industrial advances in speech recognition. Speech recognition technology permits computer access for individuals who can not use a standard computer keyboard due to neuromuscular impairment. Traditionally, individuals unable to access a computer keyboard were locked out of the work force. Speech recognition technology as a computer adaptation provides the means to eliminate this barrier. However, the model does not profess technology to be the sole solution in rehabilitation. The model goes well beyond the traditional approaches to applying speech recognition to rehabilitation which often results in the purchase of the device but not employment. The model brings together the skills of a University Based Rehabilitation Engineering Program, the State Vocational Rehabilitation Commission, and the State Project with Industry (PWI). The collaborative effort results in a program which matches the strengths of clients with the employment opportunities in the state. Speech recognition technology provides individuals with severe disabilities with the necessary means to access a computer in order to utilize their skills to accomplish a job.

BACKGROUND

There are 650,000 individuals in the United States who experience complete paralysis of all extremities due to conditions which include cerebral palsy, muscular dystrophy, spinal cord injury, multiple sclerosis, arthrogryposis, as well as other neuromuscular disorders (source from Washington D.C., Data on Disability from the National Health Interview Survey 1983-85). Of the 57,499 currently active cases listed with one northeastern state, 403 individuals are quadriplegic. In view of these stunning statistics, there are many individuals who could benefit from speech recognition technology. Speech recognition technology offers a natural means of computer control for people with writing impairments. Instead of typing, it allows individuals to speak to a computer to dictate correspondence or operate software. Eliminating the need to type, individuals who are quadriplegic face new opportunities to utilize their intellectual capacities.

There is little discussion in the rehabilitation literature on the vocational applications of speech recognition.

However, there have been several product announcements. For example, the Prabb Command 2 is a small vocabulary speech recognizer that has been marketed to enhance the vocational competitiveness of people with severe disabilities [3]. There is mention of the ability to use the Prabb Command 2 in a variety of job sites. However, there is no discussion of a model for client training or for client/employer matching.

A search in the rehabilitation engineering literature produced only a review of speech recognition devices [14], reports on speech recognition as an input for environmental control [15] and for robotic work stations [4, 17, 7]. There have also been reports on the utilization of speech recognition for Computer Aided Drafting [6] and for wheel-chair operation [11]. In fact, in a recent review article on the use of speech technology by people with disabilities [8], there is no mention of any vocational applications of speech recognition. In addition, in a study to evaluate assistive devices by the National Rehabilitation Hospital REC on Evaluation of Technology, consumers were surveyed in eleven categories [1], but speech recognition technology was reviewed only as an aid for the deaf.

Discussions with members of RECs working to develop and/or transfer technology reveal the reason for this shortage in the literature [16, 10, 2]. Although the objective of many of the RECs is to provide effective applications of assistive technology to individuals with disabilities, no REC is currently actively working on speech recognition as applied to vocational rehabilitation. For example, at the Trace Center REC on Access to Computers and Electronic Equipment, the focus is on the research and development of communication devices and access to computers using modified keyboards [9, 2]. The Trace Center's work is aimed primarily at assisting people with cerebral palsy and others who are non-verbal or speech impaired and may be inappropriate for today's speech recognition systems.

Although there has been discussion of the benefits of speech recognition technology to serve the vocational needs of persons with severe disabilities, the technology has not served all those who could potentially benefit from it. With the introduction of large vocabulary speech recognition technology in 1985, rehabilitation professionals anticipated very optimistic results on the number of individuals who would return to work [12]. Although many individuals acquired or purchased expensive technology, only a small percentage of those individuals who received speech recognizers are currently employed. Part of the problem lies with the fact that the technology has not been ready for distribution to individuals who are quadriplegic. When the technology emerged in the mid 1980's, it did not come with any applications. Those applications that were subsequently developed and vocationally useful could not be distributed because of lack of understanding how they might be integrated in to vocational rehabilitation plans. Often, individuals receiving the technology remained unemployed. Despite the impressive achievements in large vocabulary speech recognition technology, there are three reasons why this technology has had so little impact on the numbers of individuals with quadriplegia returning to work:

(1) There has been no systematic procedure for assessing clients and identifying employers.
(2) There has not been enough research performed to evaluate cost-effectiveness.
(3) Without a systematic procedure or evidence of cost-effectiveness, it has been impossible to develop a method of distribution to reach the numbers of individuals who could benefit from this technology.

OBJECTIVE

The vocational placement of an individual with a severe disability is directly related to the degree to which that person can:

- Perceive and acquire information;
- Process that information and make decisions;
- Communicate those decisions to people and environment.

While these three actions can be used to describe any work situation, they are of particular concern in vocational rehabilitation. The extent to which disability interferes with any of these determines how successfully a person with a severe disability can compete for gainful employment.

The vocational placement of clients with severe disabilities is often made difficult by the reduction in or lack of manual skills that results from their disability. Individuals whose disability results from a variety of neuromuscular disorders often have the sensory and cognitive skills to function at levels appropriate for employment. Yet, since they do not have commensurate manual skills that are also necessary, employment is extremely difficult.

Improvements in rehabilitation services, and special education, as well as heightened social awareness have resulted in increasingly large numbers of individuals with disabilities reaching the point in their lives where they are applying to state vocational rehabilitation agencies for assistance in independent living and vocational placement. Recent innovations in technology have removed the barriers to access of information and computer software. Coupled with new legislation requiring that government funded emerging technologies be made accessible to individuals with severe disabilities, technology has promised new vocational opportunities to individuals with disabilities. Despite the impressive technology now available to assure access to information, technology only provides a partial solution to the barriers individuals with severe disabilities face on the road to employment.

The model presented in this paper illustrates a comprehensive rehabilitation technology service delivery model to increase the availability of reliable and durable assistive technology that addresses the technology-related needs of individuals with disabilities. The project brings to bear important technological and industrial advances in speech recognition which can provide an individual with a severe disability with the means to productivity that can be useful in the pursuit of independence and employment.

METHOD

The model includes a systematic approach for evaluating, training and placing clients in gainful employment. The approach takes into account the economic environment and builds on the individual's strengths in matching each individual in an appropriate job in which s/he can succeed. The model utilizes a multi-disciplinary vocational rehabilitation team that develops strategies to identify the strengths of each individual, develops these strengths, and then places the person in a job that s/he can perform. The model is implemented through a collaborative effort which matches the clients served to the employment opportunities in the state. The application of speech recognition technology provides the individuals served with a means to utilize their skills to accomplish the job.

Part of the barrier to gainful employment for individuals with quadriplegia is the employer's recognition of and focus on the individual's lack of manual skills. Often, the employer's consideration of the individual stops here. The employer is often unaware of technology that can augment the individual's ability to work or how to access the resources available to this population. During the past seven years, technical innovations have provided important solutions to the vocational barriers individuals faced as a result of quadriplegia. During the late 1980's, numerous articles report a variety of strategies for accommodating limited motor ability to provide individuals with access to information and computer software (see for examples proceedings from RESNA, 1987-90). Nevertheless, the employment rates of individuals with severe disabilities remains low [13]. Rehabilitation technology service delivery models need to go beyond the application and distribution of technology and begin to integrate appropriate employment placement services as well.

The model identifies the job strengths of individuals who are quadriplegic and builds on those strengths.

The model also provides a systematic method for evaluating the job market and identifying those areas with market growth. Clients are matched to available jobs based on their own developed strengths.

Rehabilitation engineering helps facilitate the job placement by developing appropriate applications for a large vocabulary-speech recognition system for people who do not have use of their hands. Rather than pre-selecting a set of software packages that may be useful in a particular job, the model provides an appropriate framework that allows the clinical staff to study the skills of a wide variety of individuals from throughout the state and to develop a thorough understanding of the employment opportunities in the state.

From this strong basis of understanding, individuals are matched to appropriate vocational opportunities and applications are developed with intimate involvement from the potential employers.

Appropriate utilization of rehabilitation technology that results in successful vocational placements of individuals can only be accomplished through a collaborative effort of several agencies. Working cooperatively with the vocational rehabilitation centers in the state, the clinical staff implements a service delivery program for providing speech recognition vocational services to individuals with severe disabilities. A University based Rehabilitation Engineering Program works with the State Vocational Rehabilitation Agency and the State Project with Industry. This consortium provides a large client referral base. Collaboration with the State Vocational Rehabilitation Commissions which serve neuromotor impaired and blind individuals assures that individuals who have neuromuscular disorders and visual impairment benefit from the program as well.

Figure 1 shows the organization of the clinical staff and its relation to the vocational rehabilitation framework. The clinical staff works with staff from the Project with Industry to seek referrals, perform client evaluations and job placements. A Vocational Rehabilitation (VR) Advisory Panel and an Employer Advisory Panel are established. The VR Panel includes client representation, members from the clinical staff and rehabilitation consortium and representation from rehabilitation agencies in the staff. The VR Panel assures that all potential clients are referred for evaluation to the program and are realistically assessed for their vocational strengths. The VR Panel includes representation from the State Vocational Rehabilitation Agencies, students with disabilities from local universities, representation from local computer users groups, the National Spinal Cord Association, Multiple Sclerosis Society, Muscular Dystrophy Society and the United Cerebral Palsy Society. Through collaboration with a State Project with Industry, an employer Advisory Panel is established. As part of its mandate, a State PWI develops an employer base of a large number of employers in the state. The PWI works with the clinical staff to identify employers who have an expressed interest in affirmative action employment. The Employer Advisory Panel performs an advisory role of representing appropriate vocational growth areas in the state.

Clients also have a role on the Employer Advisory Panel. The Panel's involvement in the project includes identifying jobs and assistance in the design of all software applications of speech recognition. This assures that the costly procedure of application development results in software which is responsive to the employer's needs. The Employer Advisory Panel is involved early in the assessment of clients, enabling employers to develop a clear understanding of the client pool and interest in the success of seeing the clients reach gainful employment.

DISCUSSION

The model is of great significance to the State Vocational Rehabilitation Program. Although a great deal of progress has been made in the vocational rehabilitation of individuals with disabilities and although a variety of vocational services are offered throughout the states, a large number of individuals with severe disabilities are still unemployed. In an article entitled "Employment after Spinal Cord Injury [5], the authors report results for a population of 154 individuals who sustained spinal cord injury. Each individual in the group was followed for a period of seven years after injury. Only 29.9% of the individuals of that group were employed for any duration during the time of follow-up. The authors state:

"Since only 19.4% of the subjects were employed seven years after injury, it is apparent that many patients were either unwilling or unable to maintain jobs they had acquired." Despite the impressive accomplishments of the State Vocational Rehabilitation Agencies and the Project with Industries, these agencies have found it a challenge to take advantage of current technology and apply it to the real employment needs of people with severe disabilities. The model described in this paper targets a population of individuals who are presently out of the employment mainstream. A clinical staff working in coordination with other state agencies in a framework discussed above helps bring the outstanding services of Vocational Rehabilitation Agencies to a larger population of people within the state. By applying powerful speech recognition technology in an appropriate vocational rehabilitation framework, the vocational needs of individuals with severe disabilities can be met.

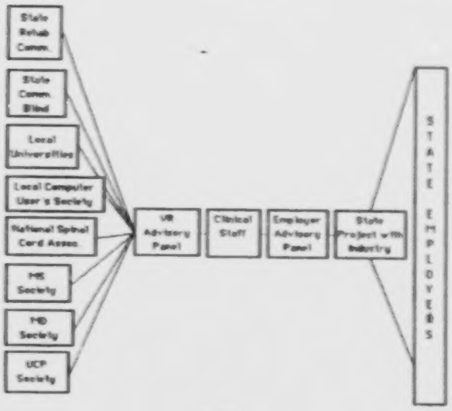


Figure 1

REFERENCES

[1] Batavia, A. and Hammer, G. (1989). "Consumer Criteria for Evaluating Assist yive Devices: Implication for Technology Transfer", Proceedings of the 12th Annual Conference for the Advancement of Rehabilitation Technology, 194-196.
[2] Borden, P. (1990). Personal Communication with the REC on Access to Computers and Electronic Equipment, Trace Center, Wisconsin.
[3] Clark, M. (1989). "A Voice-Controlled Vocational Robotic Workstation for People with Physical Disabilities", Speech Technology, Oct./Nov., 78-80.
[4] Corker, K., Lyman, J.H. and Sheredos, S. (1979). "A Preliminary Evaluation of Remote Medical Manipulators", Bulletin of Prosthetic Research, BPR 10-32, 107-134.
[5] DeVivo, R., Rutt, S., Stover, S., Fine, P. (1987). "Employment after Spinal Cord Injury", Archives of Physical Medicine and Rehabilitation, Vol. 68, August, 494-498.
[6] Robinson, J. (1989). "Computer Drafting for the Disabled", Proceedings of the 12th Annual Conference of Rehabilitation Technology (RESNA), 311-312.
[7] Horowitz, D. and Hausdorff, J. (1989). "A User Intuitive Speech Control Language for Text Processing and Robotic Task Planning", Journal for the American Voice I/O Society, vol. 6, June-July, 28-46.
[8] Mills, R. (1988). "A Survey of Speech Technology Used by People with Disabilities", Speech Technology, Sept./Oct., 56-60.
[9] NIDRR (1988). "Program Directory October 1988 for the National Institute on Disability and Rehabilitation Research", U.S. Department of Education, Office of Special Education and Rehabilitative Services, 69-77.
[10] Scadden, L. (1990). Personal Communication with the REC on Technology Transfer.
[11] Schalk, T.B. (1987). "A Voice-activated Wheel-chair", Speech Technology, Oct./Nov., 44-48.
[12] Shane, H. (1986). Personal Communication with the Communication Enhancement Center of Boston's Children's Hospital.
[13] Trieschmann, R. (1988). Spinal Cord Injuries: Psychological, Social, and Vocational Rehabilitation, Demos Publications, New York.
[14] Thomason, V., Chopra, P., Farajian, S. and Abazid, M. (1988). "Application of Voice Recognition for Computer Access and Programming", Proceedings of the International Conference for the Association for the Advancement of Rehabilitation Technology, 370-371.
[15] Thomason, V., Chopra, P. and Farajian, S. (1989). "An Integrated Voice-Accessed Communication Module for the Physically Handicapped", Proceedings for the 12th Annual Conference on Rehabilitation Technology (RESNA), 248-249.
[16] Weston, D. (1990). Personal Communication with the REC for Technology Resources, Institute of Human Resource and Development, Connecticut.
[17] Wicke, R. et. al. (1983). "Evaluation of a Speaker-Dependent Voice Recognition Unit as an Input Device for Control of a Robotic Arm", Proceedings of the 6th Annual Conference of Rehabilitation Engineering, 236-238.

Acknowledgements:
Funding for this program is provided by the U.S. Department of Education Rehabilitation Services Administration under the National Model Program on Special Projects and Demonstrations for Providing Rehabilitation Engineering and Vocational Services to Individuals with Severe Disabilities Grant #H128A01011.

Address Correspondence to:
David M. Horowitz
Rehabilitation Engineering Program
75 Kneeland Street Floor 5
Boston, MA 02111

BEST COPY AVAILABLE

7.5

A Model for Assessing the Needs of Disabled Employees in the Work Place

Jennifer Angelo, Ph.D., O.T.R.
University at Buffalo

Three physically disabled employed individuals, all with a progressive muscular disease, were evaluated to examine types of employment and the kinds of assistive devices that could be helpful to them in their work. This paper describes how the Team Resource Model was used to assist these three clients.

The Team

The team is a multi-disciplinary resource service that assesses the person as a whole. The team approach allows specialized and coordinated assessments. Through the assessments, the needs of the person are addressed, and a plan made as to how best to meet those needs through the expertise of the professionals on the team. If a need is identified which is beyond the scope of the team. A referral is made to the appropriate agency for that portions of the individual's overall needs.

The team consists of an occupational therapist, a rehabilitation engineer, and an architect. An augmentative communication specialist was available if needed. The rehabilitation engineer makes recommendations for power or manual wheelchair and seating and position for body alignment. This reduces fatigue and the effort needed to maintain an upright posture for work. The occupational therapist makes recommendations for work station modifications to provide preferable access to the office equipment. The therapist also recommends assistive devices which will improve the individuals' ability to access office equipment: computer, telephone, or tape recorder. The architect makes recommendations for work and home accessibility modifications to reduce the effort needed to travel from home to work.

Referrals

The team receives referrals from the Office of Vocational Rehabilitation and occasionally from the clients themselves. Some clients are in jeopardy of loosing their jobs if a method cannot be found to enable them to complete necessary work duties.

The Assessment and Recommendations

The Technology Resource Team assesses motor control and job tasks at the work site. After these two factors are determined, types of access devices and modifications to the worksite that will increase independence and cause less fatigue are investigated. When more than one assistive device is available, they are compared. For worksite modifications, different arrangements are examined until an ideal arrangement is found.

Clients

Selected characteristics of each individual is presented in Table One.

Subject 1's is an attorney. He holds court hearings. His main job task is writing the decisions from the hearings and using the telephone. His main concern was using the telephone independently and have private conversations. A single switch device to dial and answer the telephone was recommended. He did not need feel he needed access to a computer. His attendant is a fast typist and another set up would be slower. It should be noted that he will be retiring in a few years; this may play a role in his declining more assistive devices that would provide him with greater independence in his work.

Subject 2 works is a data analyst. Her main task was typing data into a computer. She needed the flexibility of working at home on days when she was too weak to travel to the office. She also required abbreviation expansion software to reduce unnecessary typing of commonly used words and a screen expansion software to reduce unnecessary typing of commonly used words and a screen enlarger to be used when she experiences difficulty focusing on the screen. A portable computer was recommended. A luggage carrier was also recommended to reduce the strain of carrying the computer to and from work.

Subject 3 was a data management coordinator, his job centered around being able to access a computer. He was able to use the standard IBM compatible keyboard but experienced difficultly in reaching all the keys. With his progressive disease, the keys on the periphery of the keyboard were at times beyond a comfortable reach for him. A small keyboard was recommended. He had accurate fine coordination and the keyboard was easy for him to operate.

Funding

Subject 1 is eligible for funding through the Veteran's Administration, Subject 2 through the Office of Vocational Rehabilitation, and Subject 3 is not eligible for funding through a government sponsored agency. However, his employer was willing to pay for the necessary assistive devices and workstation modifications to retain this employee.

Conclusions

The Technology Resource Team Model was effective in resolving computer interface and work station problems for three individuals'. Those problems included computer monitor placement, computer and telephone access, desk height and shape, wheelchair access. Architectural barriers which hindered access to or inside the office building and home were also addressed. The team approach was crucial in finding solutions for individuals who were in jeopardy of loosing their employment. Results indicate that a broad based team comprised of individuals with expertise in the problems and needs of disabled persons is a promising approach to the successful, continued employment for individuals with physical disabilities who desire to continue working. Assistive devices and elimination of architectural barriers allow disabled employees to continue in their role as workers for a longer period of time than they would otherwise be able.

Successful work experiences of persons with physical disabilities often requires special modifications and assistive devices. The Technology Resource Team Model provides the needed services for disabled individuals to have a successful work experience.

Address

Jennifer Angelo, Ph.D., O.T.R.
515 Kimball Tower
University at Buffalo
Buffalo, New York 14214
(716) 831-3141

Acknowledgements

Funding for this project was provided by Department of Education's Rehabilitation Services Administration's Program of Special Projects #H128A91103-89

Table 1. Subject Summary

Subject	Diagnosis	M/F	Age	College Degree	Type of Employment	Employed Full or Part Time	Attendant At Work	Mobility	Transport-ation
1	Multiple Sclerosis	M	55	Yes	Business	Full	Yes	Power wheel chair	Private
2	Multiple Sclerosis	F	27	Yes	Business	Part	No	None	Private
3	Muscular Dystrophy	M	40	Yes	Business	Full	No	Power wheel chair	Private

7.6

TECHWORKS REHABILITATION ENGINEERING SERVICES IN NEW MEXICO—TWO YEARS LATER

Scott Segner
Adelante TechWorks
Albuquerque, NM

ABSTRACT

In the fall of 1988, the New Mexico Division of Vocational Rehabilitation (DVR) began statewide rehabilitation services through a contract awarded to Adelante Development Center's TechWorks. As of the fall of 1990, over 180 clients have been served via this contract. These clients have received detailed evaluations for adaptive technology, equipment maintenance, and onsite modification of their homes and worksites. Technical support has been supplied to both clients and DVR counselors. The overall success of this contract was a key factor in TechWorks being awarded an additional contract with the New Mexico Technical Assistance Program (NMTAP). The NMTAP was set up using funds provided by the Tech Act.

OBJECTIVES

TechWorks operates according to objectives specified in the two contracts that fund the program. In summary, these include:

- Provide technical evaluations and follow-up services to clients referred by the DVR and the NMTAP.
- Maintain a shop and mobile service delivery system in order to provide these services.
- Maintain a technical library for use by staff and adaptive equipment consumers.
- Maintain a loan bank of equipment to be used for long term evaluation and as a stopgap measure during the equipment ordering process.

METHODS/APPROACH

TechWorks uses a multidisciplinary team to provide well-rounded services. The team is comprised of a Lead Engineer, an Occupational Therapist, and an Office Manager/Trainer. With the addition of the NMTAP contract, an additional Occupational Therapist has been hired and a Shop Technician/Fabricator has been added to the team. Both the Lead Engineer and the Occupational Therapist are typically involved with the initial evaluation of client's needs.

Approximately fifty percent of TechWorks' clients live outside the Albuquerque metropolitan area. These clients are served via a mobile evaluation van. This van can be quickly outfitted with the equipment necessary to evaluate a particular set of clients' needs. The van is set up with interchangeable modular equipment carts and cabinets in order to facilitate this outfitting. Evaluation road trips are scheduled considering both evaluation type and geography. The evaluation van is then loaded with the necessary equipment to perform the evaluation and/or modification work. A typical road trip includes working with eight clients over a four day period and encompasses traveling 1,000 miles.

The remaining fifty percent of TechWorks clients live in or around the Albuquerque metropolitan area. The majority of these clients are seen at TechWorks' headquarters in Albuquerque. The TechWorks facility includes office space for staff, shop facilities, a technical library, and a computer demonstration/evaluation room.

The addition of the NMTAP contract and the subsequent staff increase has made it necessary to expand the facility size. TechWorks is currently searching for a new home of approximately 3,000 square feet, or double its current size.

Following a technical evaluation, TechWorks staff issue a formal written report with recommendations to the referral source. This report contains client background information, observations made during the evaluation process, and recommendations. The recommendations section includes detailed vendor and cost information. Further TechWorks involvement is also specified in the report if needed. For instance, this might include modification of off-the-shelf equipment.

TechWorks maintains a loan bank of adaptive equipment. The purpose of this loan bank is: first, to make equipment available as a long term assessment tool; second, the equipment can be used to bridge the gap between the time that a piece of equipment is approved for purchase by a funding agency and the actual delivery of that equipment. The current loan period policy is two weeks with an extension of two weeks. The loan bank has proved to be a valuable resource in the overall operation of TechWorks.

RESULTS

By consciously including the client and referral source personnel in the problem solving process, TechWorks has enjoyed a successful start-up and operation over the past two years. The demand for TechWorks' services has steadily increased and now results in an evaluation backlog of two and a half months. Due to this backlog, TechWorks currently uses a triage system to prioritize client cases. At this point, the challenge before TechWorks is to increase capacity without sacrificing quality or attention to detail.

A sampling of case summaries:

- Several cases have resulted in implementation of at-home computer systems. The systems have been set-up to do accounting, desktop publishing, and to assist with scholastic pursuits.
- TechWorks has constructed ramps to make clients' homes accessible to both power and manual mobility.
- The combination of a hand splint and simple jigs at a work place helped double a worker's productivity in a manufacturing setting.

- TechWorks staff have been involved in ongoing training with computer and augmentative communication devices.
- Computer equipment from the loan bank has been used in college settings to provide access not available through on-campus computer labs.
- TechWorks has worked closely with DME dealers on several cases to ensure that equipment is properly selected and fitted.

REFERENCES

Bullard, J., Segner, S., and Bassan, B., "TechWorks - Rehabilitation Engineering Startup Program in New Mexico", *Proceedings of the 12th Annual Conference on Rehabilitation Technology*, June 1989, 364.

ACKNOWLEDGEMENTS

The TechWorks project is funded by contracts with the New Mexico Division of Vocational Rehabilitation and the New Mexico Technical Assistance Program. For further information, contact:

Paula Sorrell
Contracts/Grants Manager
New Mexico Division of Vocational Rehabilitation
604 W. San Mateo
Santa Fe, NM, 87503
(505) 827-3511

Andy Winnegar
Director
New Mexico Technical Assistance Program
604 W. San Mateo
Santa Fe, NM 87503
(505) 827-3533

Scott Segner
Lead Engineer
Adelante TechWorks
4906A Jefferson NE
Albuquerque, NM, 87109
(505) 889-0591.

COLLABORATION: A PARTNERSHIP FOR PROVIDING ASSISTIVE TECHNOLOGY SERVICES IN MICHIGAN

Donna Heiner / Joseph Skiba
Living and Learning Resource Centre/Michigan Rehabilitation Services

ABSTRACT

The increasing number and sophistication of microcomputer-related assistive technology devices make it imperative that purchasers have access to professionals experienced in the matching of individual requirements with the appropriate technology. Cooperation between local and state agencies can help maximize the use of financial and human resources.

BACKGROUND

In Michigan, two branches of the Michigan Department of Education are responsible for overseeing the assistive technology needs of a majority of individuals with physical impairments. Special Education Services (SES) provides leadership to educators by stimulating the use of technology, focusing statewide efforts, and stabilizing the movement of technology into special education classrooms. The Michigan Rehabilitation Services (MRS) through a network of district offices, implements an agency plan for the integration of rehabilitation engineering and rehabilitation technology into the rehabilitation process.

OBJECTIVE

The complexity of and rapid changes in assistive technology make it difficult for professionals providing direct services to formulate accurate decisions regarding the selection of assistive technology. Education and rehabilitation personnel frequently lack up-to-date information on available computer input/output devices and augmentative communication devices. Individuals in low incidence categories frequently require unique solutions. Professionals may be unaware of the advantages and limitations of certain devices in educational or vocational situations. Funding patterns and the high costs associated with technology necessitate appropriate initial decision making. In order to select technology, professionals require access to: printed and electronic databases, a central location containing a current selection of assistive technology devices and workstations, and a professional team experienced in the provision of assistive technology services.

METHOD

Funded as a State-Initiated Project by the Michigan Department of Education, Special Education Services, the Living and Learning Resource Centre (LLRC) was established as a statewide center on assistive technology.

The LLRC provides information, demonstration, and consultation to consumers, professionals, parents, and other interested individuals. Open 9-5 Monday through Friday, the Centre has a toll-free number to facilitate responding to requests for information and is TDD-accessible. Located in the Main Library of the Michigan School for the Blind in Lansing, the LLRC houses an extensive collection of augmentative and alternative communication devices, computers, input/output devices, and software. A professional staff consisting of a special educator, occupational therapist, speech-language pathologist, and sensory devices specialist provide individualized consultations on device selection. Funding is provided by State-Initiated Project funds received under the State Plan for P.L. 94-142, the Individuals with Disabilities Education Act (previously the Education of the Handicapped Act). LLRC services are therefore funded for the special education population.

Michigan Rehabilitation Services has installed a five-year accommodation plan which places in context the provision of assistive technology services. The plan includes: training of staff in accommodation and task analysis; team consultation and problem solving; the availability of consultation, decision-making, and services to the counselor; the importance of the client in the accommodation process; and the integration of other service providers.

DISCUSSION

To prevent duplication of resources, the LLRC and MRS have established a mutually beneficial relationship. Through a contractual relationship with MRS, the LLRC provides inservice training of MRS counselors and "technology evaluations" for clients requiring augmentative communication and/or adapted computer access.

As part of the accommodation plan, MRS provides all counselors, managers, and consultants with training in task analysis and accommodation. During these training sessions, participants spend an afternoon at the LLRC. After a brief introduction to the LLRC, which includes guidelines for (1) accessing the LLRC staff and (2) determining which clients may benefit from its services, attendees participate in a hands-on technology awareness session. In small groups, attendees operate a variety of assistive technology devices. A typical experience would include searching the AbleData database, using a miniature and an expanded keyboard, entering text via a single switch scan, making a telephone call with a computer, responding to questions with an augmentative communication device, writing a sentence with word prediction or abbreviation/expansion software, operating a computer with voice output capabilities, and watching videotapes illustrating new developments in technology. The purpose of the experience is not to teach the participants to select technology, but rather to alert them to the fact that many possible technology options exist.

The LLRC also provides individualized consultations for MRS clients who may require assistive technology for vocational purposes. After counselor, client, and LLRC staff determine that the LLRC is the appropriate facility, a morning or afternoon consultation is scheduled. Two to four LLRC staff members assist client and counselor to further clarify technology needs, suggest possible alternatives, and provide the client with the opportunity to experiment with the hardware or software. Following the consultation, counselor and client receive a report detailing observations and suggestions.

This collaborative effort between two state agencies providing assistive technology services to students and adults has resulted in maximizing the utilization of available resources.

REFERENCES

Michigan Department of Education, Special Education Services. Special Education Services Technology Plan: 1990-1995: The Concept and the Implementation. Internal Working Document.

Michigan Department of Education, Michigan Rehabilitation Services, Rehabilitation Technology Implementation Plan. 1988.

Donna Heiner, Director
Living and Learning Resource Centre
601 W. Maple Street
Lansing, MI 48906
(517) 487-0883

Joe Skiba
Michigan Department of Education
Michigan Rehabilitation Services
PO Box 30010
Lansing, MI 48909
(517) 373-4032

8.1

The Function of Function Words and Function Units in Augmentative Communication

Steven Ray, Ed.D.
Adaptive Communication Systems, Inc.
Pittsburgh, PA

Abstract

Methods of accelerating speech output and speech recognition within augmentative communication devices are proposed. The methods are based on coding of "function words" and "function units" within speech output devices. In speech recognition technology, function units are treated as words to improve both speed and accuracy of recognition. The system of codes and function units require minimal skills to master.

Background

Although variously defined, linguists have long recognized the significance of distinguishing between "functors" or "function words" and "contentive" or "content words" in the description of language (Brown and Fraser; 1963; Brown and Bellugi, 1964; Brown, 1973; and Fries, 1963). The set of function words generally, but not always, includes articles, prepositions, pronouns, conjunctions, auxiliary verbs and modals. For the purpose of this article the set of function words will be defined as those words in our language which are static and not subject to growth in number. The set of words in our language which is subject to growth is the set of content words. These generally include nouns, adjectives, adverbs and verbs. The set of function words is finite and universal as contrasted with the set of content words which is infinite and personal.

Statement of the Problem

Although the set of function words is quite limited, the frequency of occurrence of function words in our language is very high. Function words can account for 65-75 percent of all words in oral and written sample of children and adults. In one study (McNally and Murray, 1962) it was found that only 12 words could account for 25% of the words we read. These were *all, as, at, be, but, are, for, had, have, him, his, not, on, one, said, so, they, we, with and you*. All but one of these words (said) are function words.

Function words frequently occur together within a sentence. Since these sequences of function words do not adhere to linguistic conventions of phrase structure rules, they represent a previously unrecognized concept. Thus, the "function unit" will be defined as two or three contiguous function words and the use of the term phrase is intentionally avoided. Since the set of function words is finite, the set of function units, although large, is also considered finite. To date the author has identified over 1500 function units. Preliminary estimates indicate that nearly 30 percent of our language consists of these units regardless of context.

Approach

Advantage can be taken of these rather powerful words and their combinations into units in augmentative and alternative communication. Since they are finite and common to the language of all speakers, they are useful regardless of the context, content or mode of our utterances.

When searching for a method of accelerating the communication process of orthographic users, (spellers) these words become obvious targets for abbreviations. The irony, however, is that although they are a powerful set of words, these words are also very short. Most function words are five characters or less in length.

Published in a Vanderheiden and Kelso article (1987), an alphanumeric, optimized, ideological coding system for representing the most frequently encountered words in the English language was presented. An analysis of the total percent of keystrokes eliminated for this set of single words produced a savings of about 44 percent.

These codes have been implemented on augmentative devices capable of abbreviation expansion and proven to be both powerful and easy to learn. Some samples of these codes are as follows:

Code	Meaning
2	to
4	for
8	it
b	but
cn	can
cd	could
wz	was
dz	does
m	me
u	you
v	have

It was discovered that additional keystroke savings could be achieved by combining these function word codes into units of two or three elements.

These combinations, however, carry with them modest learning costs to the user. That is to say, once an individual learns the eighty or so codes in the first system, they are merely combined or executed, without the space between them, to produce function units. Another important feature of these units is that they are internally redundant. Thus, the function unit of *You can have* consists of two other possible units of *You can* and *can have*. This redundancy reduces the demand on the user to recognize the complete function unit. Thus, the user could produce the codes for each element separately (*u cn v*) and achieve a keystroke savings of 5, produce the codes for the two possible two-element units (*ucn v* or *u cnv*) for a savings of 7, or produce the most efficient sequence containing all three elements (*ucnv*) for a maximal savings of 8 keystrokes.

Using a core vocabulary of only 80 codes, representing the 80 most frequently used words in English language samples (Vanderheiden and Kelso, 1987), a total of more than one thousand codes can be stored for function units with fewer than ten collisions or conflicts between codes. Such a system has already been implemented on the RealVoice (1990) communication device. The following are samples of these codes:

Code	Meaning
du	do you
ud	you do
iv	I have
dz8	does it
ru	are you
wydd	why did
wydu	why do you
urdg	you are doing
hhzhd	he has had
ivhd	I have had

Elsewhere strategies have been described for the coding of content words and frequently used sentences. These strategies include special markers for categories of words when coding content words and markers for tense, number and aspect for frequent sentences (Ray, Morris & Palin, 1990).

Function units can also be used in speech recognition systems. Dragon Dictate (1990) is a discrete word, large vocabulary speech recognition system. Each word is produced individually and the system attempts to guess the word and offers the user a choice of up to 10 words from which to choose each time. Again, ironically, the hardest words for this system to recognize are the function words. This is true because they carry very little acoustic information. Thus, the word *education* is much less difficult to recognize than the word *I* which can be mistaken for *eye, bye, my, by, aye, etc.* Each decision which must be made by the user reduces the speed of input for such a system.

If the system is given function units to be handled as words, then both speed and accuracy of recognition is increased. Again the redundancy of elements within the function units reduce the metalinguistic demands for recognizing *full* function units. For example: "Do you have the car" can be segmented as; Do you - have - the - car, Do you have - the - car, Do you - have the - car, or Do - you have the - car.

Implications

Augmentative communication device users who use orthography as an input method for their speech prosthesis can easily learn a small set of less than 100 function words and their logical letter codes. These codes can, with little effort, be combined into function units for additional keystroke savings and more efficient communication. This system represents a standardized method of coding a powerful set of words and combinations of words while avoiding the pitfalls of developing idiosyncratic systems which generally produce large numbers of collisions.

When the function unit is programmed into speech recognition systems as words or single elements, they enhance the recognition accuracy of the system. In addition they reduce the number of choices required during the diction process.

The redundancy of function units enhance their power while reducing the metalinguistic and cognitive demands for recognition. Thus, the system of coding function units is both powerful and forgiving.

Conclusion

By tightening the definition of "function words" and ignoring traditional phrase structure grammars, a newer and more powerful linguistic unit has been identified. The function unit has potential for improving the efficiency of communication of augmentative communication device users. The function unit can be applied to both speech output systems and speech recognition systems. This technique draws upon previously established orthographic skills and requires minimal metalinguistic skills. Research is currently underway to quantify the advantages of utilizing these units.

References

1. Adaptive Communication Systems, Inc. (1990). RealVoice SpeechPac. Pittsburgh, Pennsylvania.

2. Brown, R. (1973). *A first Language: The Early Stages*. Cambridge: Harvard University Press.

3. Brown, R., and Bellugi, U. (1964). Three process in the child's acquisition of syntax. *Harvard Educational Review*, Vol. 34 No. 2, Spring 1964, 133-151.

4. Brown, R. & Fraser, C. (1963). The Acquisition of Syntax. In C.N. Cofer and B. Musgrave, (Eds.) *Verbal Behavior and Learning: Problems and Processes*. New York: McGraw-Hill, pp. 158-201.

5. Dragon Systems (1990). Dragon Dictate (1990).

6. Fries, C.C. (1963) *The structure of English*. London: Longmans.

7. Jackson, T. W. & Clegg, J. H. (1988). Strategies for the Teaching of Vocabulary Based on Oral Frequency Counts. In J. F. Lalande, (Ed.), *Shaping the Future of Language Education: FLES, Articulation, and Proficiency*. Report of Central States Conference on the Teaching of Foreign Language.

8. McNally, J., & Murray, W. (1962) *Key words to literacy*. London:Schoolmaster Publishing Company.

9. Ray, S., Morris, N.T. & Palin, M.W.(1990). *Letter Coding and Letter Coding Strategies for AAC Users*. In press.

10. Vanderheiden, G.C. & Kelso, D.P. (1987). Comparative analysis of fixed-vocabulary communication acceleration techniques. *AAC Augmentative and Alternative Communication*. 4, 196-206.

11. Wiegel-Crump, C.A. (1979). Rehabilitation of Acquired Dyslexia of Adolescence. In T.G. Waller & G.E. MacKinnon (Eds). *Reading Research: Advances in Theory and Practice, Vol.1*. New York: Academic Press, 171-185.

Steven Ray, Ed.D.
Adaptive Communication Systems, Inc.
P.O. Box 12440
Pittsburgh, PA 15231

Automatic Abbreviation Generation

Gregg M. Stum, Patrick W. Demasco, and Kathleen F. McCoy
Applied Science and Engineering Laboratories
University of Delaware/Alfred I. duPont Institute
Wilmington, Delaware USA

Abstract

This work is part of an augmentative communication project being conducted at the Applied Science and Engineering Laboratories of the University of Delaware and the A.I. duPont Institute. The goal is to reduce the demands of traditional abbreviation expansion systems, on both the clinician and the client, by providing a clinical aid for constructing a fixed set of abbreviations for a vocabulary, and a user tool for recognizing a variable set of abbreviations for a vocabulary item. To this end an abbreviation generator produces all the possible abbreviations associated with a vocabulary under a well defined model of abbreviation.

Background

An abbreviation expansion system is usually a computer-based typing tool that replaces a sequence of characters, representing an abbreviation for a word, with that word. The set of abbreviations associated with a vocabulary is an abbreviation scheme. An abbreviation strategy is the rule or set of rules used in forming the abbreviation.

Vanderheiden and Kelso [5] identify abbreviation expansion as an important technique in an acceleration vocabulary of an individual using a communication aid. They show that a relatively large amount of communication is composed of a relatively small number of words, and that there is a high degree of consistency in this set of the most frequent words among different users. After analyzing several abbreviation schemes for this vocabulary, they find their idiosyncratic-logical scheme the most effective.

As illustrated by this study, choosing a good abbreviation scheme for a specific vocabulary requires considerable research time and effort. For a set of the most frequently used vocabulary items this investment is worthwhile since the set is essentially fixed. However, this set only constitutes the majority of text produced, not its totality. The remaining portion is drawn from a variety of context-specific vocabularies, that may be different among individuals.

Thus a specific vocabulary is not uniformly appropriate to all users. This means that the clinician is responsible for constructing abbreviation schemes for a number of clients. This task is even more ominous considering that the abbreviations must be tailored to the client and that different clients have different preferences about how something should be abbreviated. So a specific scheme for a vocabulary is not uniformly appropriate, and the task of generating abbreviations that are easy for each client to recall is enormous.

Statement of the Problem

For each user of an abbreviation expansion system a vocabulary of words to be abbreviated must be specified, and the individual abbreviations for the words determined. This requires knowledge in constructing abbreviation schemes, consideration of the user's cognitive skills, physical abilities, and abbreviation preferences, and the time and effort of the clinician. These requirements are not generally insignificant.

Once a scheme is established for a vocabulary, the user must either memorize it, or have it available to reference. For any scheme of appreciable size, the cost of cognitive load or lookup time is significant, and may in fact exceed the savings in keystroke reduction.

These considerations identify two basic related problems: the construction of an effective abbreviation scheme for a given vocabulary; and the overhead imposed on the user of such an abbreviation scheme.

Approach

The *abbreviation scheme constructor* provides to the clinician several sets of fixed abbreviation assignments for a vocabulary, with each of these schemes representing the application of a specific abbreviation strategy. From these, the clinician selects the most appropriate scheme for a specific client. The *adaptive flexible abbreviation expander* obviates the need for any fixed scheme by recognizing any well-defined abbreviation for a vocabulary item with roughly the same speed as a fixed abbreviation expander. Naturally, expansions for such abbreviations are generally not unique. This expander presents a list of the most preferred expansions based on human preferences and the user's history. The *automatic abbreviation generator* is a preprocessor for both the constructor and the expander that provides their required information and reduces their run-time computational requirements to make implementations practical. The generator does not use strategies in producing the abbreviations, but rather it rates an abbreviation according to the strategy it best represents for the word from which it was obtained.

The Basic Abbreviation Context

In order to identify the fundamental design and implementation issues in creating the generator, a basic model of the abbreviation context is defined. This model is intended to be only sophisticated enough to exhibit the computational requirements without being complicated by features that might be desired in an implementation, but do not contribute to its computational complexity. These features are then supported as extensions to the basic model.

With these objectives, the model is this. The vocabulary being abbreviated consists of single word items. An abbreviation is taken to consist of only letters from the word appearing in the same relative order as in the word. Thus, the number of possible abbreviations for a given word of length n is 2^n-1. The important characteristic to note is that this number grows exponentially on the length of the word.

Extensions

Examples of extensions to the basic abbreviation model include: using numerals, special characters, and letters not appearing in the word for phonetic or mnemonic value; and allowing phrases, utterances, and templates for them as vocabulary items. None of these extensions change the exponential nature of the number of possible abbreviations, and are accommodated by the generator.

The Automatic Abbreviation Generator

The generator has a rather straightforward design. It takes each vocabulary item, produces its set of possible abbreviations, and stores this set in an expansion table. Each abbreviation in the table indicates both the word from which it was obtained, and the abbreviation strategy it most closely represents for that word. It is often the case that an abbreviation represents the application of several strategies. When the same abbreviation is produced from more than one word, its entry in the table indicates a list containing all the words from which it was obtained. This list is maintained in sorted order according to preference ratings assigned to the various abbreviation strategies. Extensions to the basic model are incorporated into the generator by the use of special auxiliary functions. Each special function encodes a specific extension and is invoked by the generator as required.

Implications

The Abbreviation Scheme Constructor

An abbreviation strategy is taken to be a rule used consistently across the entire vocabulary. Only one rule is used and this rule is applied to each word. Ehrenreich [2], Hodge and Pennington [3], and Streeter, Ackroff and Taylor [4], have all demonstrated regularities in human generation of abbreviations for a given vocabulary item, and preferences for particular abbreviation strategies.

The three most basic strategies identified in all these studies are: truncation, vowel-deletion, and combination. Truncation is taking a prefix of the word. Vowel-deletion is eliminating all occurrences of vowels in the word. Combination is first an application of vowel-deletion, then truncation of the result to a maximum length if necessary. These strategies are taken as the basic model for the constructor, with more complex strategies included as extensions.

The constructor is a clinical tool used by a clinician in preparing a communication aid that includes a fixed abbreviation expander. The clinician identifies the user's vocabulary and selects the strategies to be represented. The constructor then gives an abbreviation scheme for each strategy specified. After reviewing these various alternatives, the clinician selects the most appropriate scheme for the user. If possible, this scheme is sent automatically to the fixed abbreviation expander; otherwise it is entered manually. Figure 1 illustrates this process.

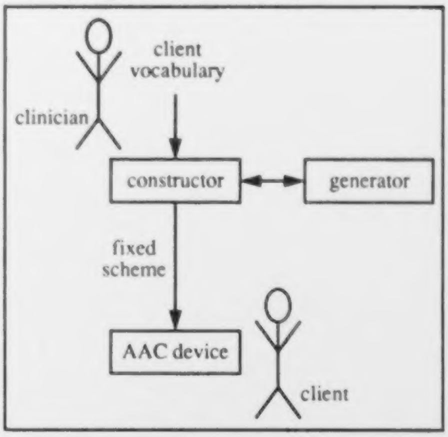


Figure 1. The Abbreviation Scheme Constructor produces a fixed abbreviation scheme for the expander of an AAC device.

The Adaptive Flexible Abbreviation Expander

A major drawback of fixed abbreviation schemes is the cost of cognitive load or lookup time imposed on the user. An expander that does not require a predefined abbreviation scheme, can deal efficiently with a *set* of well-defined abbreviations for a word, and can adapt to both the user's preferences and vocabulary, has the promise of giving the user an effective means for realizing meaningful keystroke savings.

The basic model of the expansion is that as the user types each letter of the abbreviation, the expander presents, separate from the text, a menu of some number of possible expansions for the abbreviation so far. The user then presses a key associated with the desired expansion. If the desired expansion is not presented, the user either types a special key for more expansions, or types another letter of the abbreviation. The expander then records this selection and replaces the abbreviation with the expansion. This model is intended only to demonstrate the expander's adaptiveness and flexibility. Its user interface is an entirely seperate issue and does not impact on its design.

The expander is a gateway to some other software application, such as a communication aid. As with the constructor, the user's vocabulary must be identified, and in this case given to the generator. The generator then passes the resulting sets of abbreviations to the expander. Figure 2 illustrates this process.

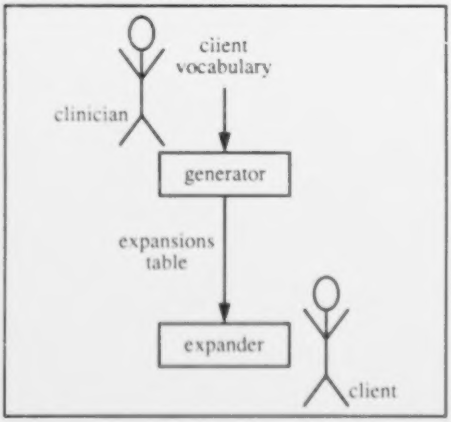


Figure 2. The Adaptive Flexible Abbreviation Expander serves as the expander of an AAC device

Discussion

This work is an extension of word compansion as described in Demasco, Lillard, and McCoy [1]. In word compansion, all the work in interpreting an abbreviation occurs at run-time. That is, after the compansion expander is given an abbreviation, it both manipulates this abbreviation and filters subsets of possible expansions from the dictionary. This interpretation is rather computationally expensive, especially compared to the simple table lookup of fixed abbreviation expansion. The objective of the adaptive flexible expander is to eliminate this disparity by moving the computationally expensive work to the generator, leaving only a table lookup and some optional bookkeeping for the expander.

The constructor represents applying knowledge about human abbreviation behavior to the results of the generator. For users not having sufficient cognitive ability either to appreciate the expander's flexibility, or to adjust to its adaptiveness, a fixed abbreviation expander is more appropriate. In this case, the constructor is a useful clinical aid for tailoring the fixed abbreviation scheme to the user.

Implementation considerations have a direct bearing on the actual limits of the generator. By design it has a high order of computational complexity. That complexity comes from both the problems it is addressing, and the fact that it is taking the computational burden away from the constructor and the expander. Given that the generator itself is not required by the run-time system, it is reasonable to assume that it runs on a hardware platform containing a large memory, a fast processor, and a large, fast secondary storage like a disk. The actual values of these parameters affect the limits of the generator's performance. A prototype of the generator is currently being used to examine basic implementation properties such as reasonable limits on the size of the vocabulary, length of vocabulary items, and number and choice of abbreviation strategies supported.

Acknowledgments

This work is supported by Grant Number H133E80015 from the National Institute on Disability and Rehabilitation Research. Additional support has been provided by the Nemours Foundation.

References

1. Demasco, P., Lillard, M., and McCoy, K. (1989). Word compansion: allowing dynamic word abbreviations. Proceedings of the RESNA Twelfth Annual Conference, 282 - 283.
2. Ehrenreich, S. L. (1982). Computer abbreviations: evidence and synthesis. Human Factors, vol. 27, no. 2, 143 - 155.
3. Hodge, M., and Pennington, F. M. (1973). Some studies of word abbreviation behavior. Journal of Experimental Psychology. vol. 98, no. 2, 350 - 61.
4. Streeter, L. A., Acroff, J. M., and Taylor, G. A. (1983). On abbreviating command names. The Bell System Technical Journal, 62, 1807 - 1826.
5. Vanderheiden, G. C., and Kelso, D. P. (1987). Comparative Analysis of Fixed-Vocabulary Acceleration Techniques. AAC Augmentative and Alternative Communication, vol 3, no. 4, 196 - 206.

Contact

Gregg M. Stum
Applied Sciences and Engineering Laboratories
A. I. duPont Institute
PO Box 269
Wilmington, DE 19899
Email: stum@asel.udel.edu

THE EFFECTIVENESS OF WORD PREDICTION

Heidi M. Horstmann and Simon P. Levine
Rehabilitation Engineering Program, Department of Physical Medicine and Rehabilitation
University of Michigan

Abstract

Comparisons of user speed on AAC systems with and without word prediction support the view that the cognitive and perceptual processes involved in use of word prediction may counteract the gains in selection efficiency. These processes and their associated time requirements are analyzed, using results from the field of human-computer interaction, as a first step toward a comprehensive understanding of word prediction's effectiveness. The ultimate goal of this work is to develop an analytical modeling framework that can be applied to any user-system interface.

Background

The past decade has witnessed a tremendous amount of clinical and research interest in the use of word prediction as a means of enhancing rate in augmentative communication (AAC) systems. While there are a number of different types of word prediction, the basic technique takes advantage of the redundancy in the English language to predict a set of words that are the most likely candidates for user entry. Word prediction choices are typically displayed in a short list and are refined as the user inputs additional letters. If the desired word is found in the list, it can be selected with one additional input, eliminating the need to select each letter individually.

Since the development of the first prototypes, much effort has gone into improving the predictive algorithms (1,16) and commercializing the systems for widespread use (5). Current systems employ improved algorithms which are capable of learning the pattern of a user's word usage. Future systems promise to go beyond statistical usage tables to utilize inferences about semantics and pragmatics (18).

Statement of Problem

A critical question is: Just how much performance improvement can be expected using word prediction? Unfortunately, the answer is that nobody knows for sure. Many researchers have tried to address the question by comparing the efficiency of systems with and without word prediction. Common metrics of comparison are keystroke savings for direct select interfaces (16), or combined savings in scan steps and switch hits for scanning interfaces (3). Theoretical simulations show efficiency gains of 24-70% (3,16), depending on the characteristics of the entered text and the word dictionary. Maximum efficiency has been estimated at 82%, under the assumption that each word can be selected with only one keystroke (16). Studies on actual users report efficiency gains of 23-47% (1,13). Based on these data, it's tempting to conclude that word prediction will universally enhance a user's text entry rate by at least 25% and possibly 50%.

However, comparisons of text entry rate with and without word prediction show that word prediction techniques do not work as well in practice as they do in theory. Experimental measurements on subjects with disabilities have demonstrated no improvement (13) or only modest (3-10%) improvements (3). At least one clinical case study has confirmed that while efficiency may improve significantly, text entry speed may not (17).

These data quantitatively confirm what has long been known: decreasing the number of necessary selections may increase the time required to make each selection, leading to unknown effects on overall performance (4,7,14). This does not mean that word prediction *never* enhances rate. It merely points out that the claims that word prediction is "time saving" (5), "increases typing rate" (6), and provides "quicker access" (12) need to be examined more closely in order to determine when they hold true and when they do not.

Approach

There are three main questions that need to be answered in order to rigorously understand the trade-off between efficiency and selection time. These are:

1. What are the factors that contribute to an increase in selection time?
2. What are the time requirements associated with each of these factors?
3. Can we determine a cross-over point between rate enhancement and rate inhibition by integrating this information with the efficiency data?

While the definitive answers to these questions require further research, there is a significant body of literature in the field of human-computer interaction (HCI) that can be fruitfully applied today, as demonstrated below.

Factors Affecting Selection Time

Use of a word prediction feature requires additional cognitive and perceptual processes, and these are the major contributors to the increase in selection time. Processes that are frequently cited include the visual search of the prediction list and the subsequent decision about whether the list contains the desired word (7,14,17). Additionally, an often overlooked source of cognitive load is the processing involved in planning use strategies and guiding overall activity (2,9). For example, the user may spend time deciding whether or not to search the list at all. Not all users will employ this strategy, choosing instead to either search every time or not at all; however, many users may adjust their use of word prediction based on their perception of the recent success rate (17). As a second example, some users may exhibit noticeable delays if the word is not found in the list, which may correspond to the processing required to shift the current task from one of recognition to text generation (17).

Word prediction may also affect the act of physically making a selection, once all decisions have been made. In the case of a keyboard-based system, motoric time may increase if the keys added for selection of word prediction choices are significantly more difficult for the user to access. In a scanning system, motoric time depends on the switch hit time as well as the scanning distance to the selection, and this distance is likely to be reduced using word prediction.

Associated Time Requirements
The times required for each of these component actions may vary widely between AAC users. However, many of these processes can be quantified based on the experimental performance of able-bodied subjects; this approach provides a "best-case" baseline and can be expected to apply to AAC system users who have cognitive and perceptual abilities within normal limits.

Several HCI studies have been performed on the visual search of lists, in which subjects search for a given target word and make some motor response to choose the target (8,15). The response times reported, when corrected for the motor time, provide estimates of the time spent in visual search and target recognition. For short lists (around five items), ordered either alphabetically or by frequency of use, search times after some practice are 1.0-1.5 seconds (8,15) and may be expected to increase logarithmically if more items are added to the list (8). With substantial practice, it may be possible to achieve search times of 0.5 seconds, although this estimate has not been validated (7).

The other cognitive processes discussed above are not as directly quantifiable, although relevant HCI work can supply approximations here as well. First, since the user of a word prediction system is faced with a choice of text generation methods (either to search the list or ignore it), times measured for choosing between methods in other domains indicate how long this decision might take. In a study of expert spreadsheet users, subjects consistently took an average of 1.76 seconds just to choose whether to type or point to cells in entering a formula (9). Other work has estimated cognitive processing of this type to take 0.62-1.35 seconds (2). Second, the amount of time required to shift attention from word recognition to text generation can be estimated using an established model of human information processing (2). While the details of the model are beyond the scope of this paper, the cognitive shifting task can be considered to require one cycle of the "cognitive processor" (2), or about 0.1 seconds, for a skilled user without cognitive deficits. While these specific estimates are little more than educated guesses at this point, the basic concept -- that unobservable cognitive processes take measurable and sometimes lengthy amounts of time -- has been well-validated in studies of HCI (2,9,10).

Finding the Cross-over Point
A primary goal is to establish methods that can define the cross-over point between rate enhancement and rate inhibition in terms of system parameters and user characteristics. One approach to this is to gather more data on users' speed with and without word prediction and attempt to draw some general conclusions based on the results. However, while this approach may successfully determine cross-over points for specific user and system characteristics, it cannot make predictions about how changes in either the user or the system will affect the cross-over point.

A more comprehensive approach attempts to create an analytical framework that integrates system and user factors and supports the simulation of unlimited user-system combinations. Preliminary work has demonstrated the use of one such framework to make theoretical predictions about user performance with and without word prediction (7). Model simulations predicted that text entry speed with word prediction would usually be lower than speed using letters only, using parameter values like those discussed above. Other investigators have also explored analytical modeling techniques, with similarly interesting results, that demonstrate the potential power of the modeling approach to address the numerous trade-off issues that exist in AAC (e.g., 3,4).

The following example illustrates one type of simple analysis that can be done with modeling, using the timing parameters estimated above. First, for a keyboard-based letters-only system, text entry speed can be estimated at $(5.7)(T_k)$ seconds/word, given 5.7 letters/word and T_k as the user's keypress time. If word prediction is added, with a keystroke savings of 50%, text entry speed becomes $(2.85)(T_{cp} + T_k)$, where T_{cp} is the time spent on cognition and perception for each selection. Assuming T_k is the same for both systems, the equations predict that the letters-only system will be faster for all $T_k < T_{cp}$. Using best-case timing values, and assuming all processes occur in series (2), T_{cp} is 1.22 seconds, which implies that word prediction will not enhance rate for individuals whose keypress time is less than 1.22 seconds. Note that this example is only an illustration of the approach, and continued research is necessary before specific values can be applied in practice.

Implications

A major implication is the need for a shift in research focus from system development to user-system interaction (11). Specific questions that need attention include:

1. Do users actually perform all the processes discussed above? If not, why not?
2. How much time does each process really take? And what is the individual variation?

3. How do the times add up? Are processes performed serially, or partially in parallel?
4. How well do model simulations predict actual performance?

Answers to these questions require a great deal of empirical measurement and observation. The key point is that, in addition to measuring the overall performance, we assess the individual contributions of the component actions that produce that performance, in order to build a foundation for a general modeling technique.

Although much research remains to be done, these ideas have practical implications today. For AAC clinicians and users, an awareness of the cognitive and perceptual costs that may be introduced with word prediction provides an important balance to manufacturers' claims and can help the user make a more informed decision. For system developers, application of the ideas within the relevant HCI literature could result in significant design improvements.

Discussion

An important limitation of this approach is that while its primary focus is text entry rate, there are numerous additional factors that determine the ultimate success of any AAC system. For example, users may express preference for a word prediction system because it helps their spelling, regardless of its effects on sheer speed (17). Additionally, improving physical efficiency may reduce fatigue for some users, allowing them to work longer or more comfortably. Finally, a user may just have a personal preference for a particular system. The optimal mix of text accuracy, user fatigue, and communication speed depends greatly on the specific goals and abilities of the user and achieving this requires a combined effort of clinician and user. However, a framework that provides an understanding of the factors that determine text entry speed and predicts the speed that may be accomplished with practice would provide a significant contribution to this effort.

References

1. Bentrup, J.A. (1987). Exploiting word frequencies and their sequential dependencies. *Proc. of 10th Annual RESNA Conf.*, Washington, D.C.: RESNA, 121-123.
2. Card, S., Moran, T., and Newell, A. (1983). *The Psychology of Human-Computer Interaction.* Hillsdale, NJ: Lawrence Erlbaum Associates.
3. Gibler, C.D. and Childress, D.S. (1982). Language anticipation with a computer-based scanning communication aid. *Proc. of the IEEE Computer Society Workshop on Computing to Aid the Handicapped*, Charlottesville, VA, 11-15.
4. Goodenough-Trepagnier, C. and Rosen, M.J. (1988). Predictive assessment for communication aid prescription: motor-determined maximum communication rate. In Bernstein, L. (Ed.), *The Vocally Impaired*. Philadelphia: Grune and Stratton.
5. Gorgens, R.A., Bergler, P.M., and Gorgens, D.C. (1990). HandiWARE. *Proc. of RESNA 13th Conf.*, Washington, D.C.: RESNA, 43-44.
6. Gunderson, J. and Vanderheiden, G. (1988). One-screen multiplexed keyboard for transparent access to standard IBM PC software. *Proc. of ICAART 88*, Washington, D.C.: RESNA, 378-379.
7. Horstmann, H.M. and Levine, S.P. (1990). Modeling of user performance with computer access and augmentative communication systems for handicapped people. *Augmentative and Alternative Communication, 6:4*, 231-241.
8. Landauer, T.K. and Nachbar, D.W. (1985). Selection from alphabetic and numeric menu trees using a touch screen: breadth, depth, and width. *Proceedings of CHI '85*, New York: ACM, 73-78.
9. Olson, J.R. and Nilsen, E. (1988). Analysis of the cognition involved in spreadsheet software interaction. *Human-Computer Interaction, 3:4*, 309-350.
10. Olson, J.R. and Olson, G.M. (1990). The growth of cognitive modeling in human-computer interaction since GOMS. *Human-Computer Interaction, 5*, 221-265.
11. Rosen, M.J. (1989). Editorial. *Assistive Technology*, 1:79-80.
12. Rowley, B.A. (1988). Interfacing the disabled to computer software through virtual interfaces. *Proc. of ICAART 88*, Washington, D.C.: RESNA, 380-381.
13. Scull, J. and Hill, L. (1988). A computerized communication message preparation program that "learns" the user's vocabulary. *Augmentative and Alternative Communication, 4:1*, 40-44.
14. Soede, M. and Foulds, R.A. (1986). Dilemma of prediction in communication aids and mental load. *Proc. of 9th Annual RESNA Conf.*, Washington, D.C.: RESNA, 357-359.
15. Somberg, B.L. (1987). A comparison of rule-based and positionally constant arrangements of computer menu items. *Proc. of CHI+GI '87*, New York: ACM, 255-260.
16. Swiffin, A.L., Arnott, J.L., Pickering, J.A., and Newell, A.F. (1987). Adaptive and predictive techniques in a communication prosthesis. *Augmentative and Alternative Communication, 3:4*, 181-191.
17. Treviranus, J. and Norris, L. (1987). Predictive programs: writing tools for severely physically disabled students. *Proc. of 10th Annual RESNA Conf.*, Washington, D.C.: RESNA, 130-132.
18. Yang, G., McCoy, K., and Demasco, P. (1990). Word prediction using a systemic adjoining grammar. *Proc. of 13th Annual RESNA Conf.*, Washington, D.C.: RESNA, 185-186.

Address

Heidi M. Horstmann
Rehabilitation Engineering Program
1C335 University of Michigan Hospital
Ann Arbor, Michigan 48109-0032, USA

SPELLER: AN ALTERNATIVE SPELLING CORRECTION SYSTEM

Andrew G. Wright, Alan F. Newell & Ian W. Ricketts,
Microcomputer Centre, Dept. of Mathematics and Computer Science,
University of Dundee, Scotland, UK.

ABSTRACT

Correction of spelling errors has become a standard part of commercial word processing systems. However, these systems were designed for office use, where mistypings occur more frequently than actual spelling mistakes. This paper describes an alternative system, which is specifically designed for users who have serious spelling disorders. The system has been successfully piloted in schools and performed favourably when tested against commercial software.

BACKGROUND

The author is part of a team who have been conducting investigations into devices which aid users with a variety of communication disorders, in particular the PAL prediction system (1), which had been found to be of considerable help to users with spelling disorders, enabling them to increase both their speed of output and quality of presentation. However, it was felt that it would still be useful to design a system which could operate in conjunction with PAL, and correct any errors which had occurred in the text output despite the use of the PAL system.

STATEMENT OF THE PROBLEM

The program would be required to analyse any entered misspellings, and to present a list of suggested corrections to the user, based on its internal dictionary list of acceptable words. The production of suggested corrections would have to take into account the nature of characteristic errors made by spelling-disordered users.

RATIONALE

Previous studies into the problem of spelling correction have tended to concentrate on two particular areas. In papers (2) and (3), it was assumed that the misspelling had one error, which would be a wrong, missing, or extra letter or a single transposition of letters, and so potential corrections would differ from the initial spelling by only one of these error types. This work was extended in (4) and (5) where algorithms were given to determine the 'distance' between two strings as the minimum number of 'edit operations' required to transform one string into the other. In (6) and (7), a system of phonetic coding was employed which attempted to ensure that spelling variations of names for example 'Smith' and 'Smythe' would be converted to the same code. The authors have sought to create algorithms which would not only perform processes similar to those in (2,3,4,5) (as employed by many standard commercial spelling checkers) but also to handle phonetic checking in a more thorough manner than previously attempted in this area.

DESIGN

The Speller system was designed to operate on an IBM PC or compatible computer, in particular the Zenith Z181 portable. The program would be primarily required to search through an ASCII text file matching each word against entries in a dictionary of approximately 5500 words. An initial study of work produced by schoolchildren with spelling problems led to the conclusion that most of their errors could be divided into two classes:

i) lexical errors where the majority of the letters in the misspelling corresponded to the letters in the intended word e.g. 'Eglis' for 'English';

ii) phonetic errors where the spelling was incorrect, but the misspelling sounded close to the intended word e.g. 'eggriclchr' for 'agriculture'.

It was therefore decided that on encountering a string which the program is unable to find in its dictionary, the program would perform two processes:

i) to search for words where the letter content was considered to be sufficiently close to that of the misspelling (and also, to a lesser extent, the letter order);

ii) to search the dictionary for appropriate phonetically close words.

DEVELOPMENT

It was decided that in order to find phonetic matches, it would be appropriate to break down each word into its constituent phonemes and perform a comparison of the phonemes in the misspelling against the phonemes contained by words in the dictionary, and in this way search for words with high phonetic similarity to the misspelling. For this purpose, a text-to-phoneme conversion system was developed. A rulebase (8) developed for the purpose of text-to-phoneme conversion was adapted to make it relevant to the sounds and pronunciations in 'British English' rather than 'American English'. Approximately 100 rules were added to increase the accuracy of the rulebase. Using the rulebase, a phonetic representation of the entire resident dictionary was compiled, so both a dictionary of words and a parallel associated phonetic dictionary could be held in memory simultaneously. To compare two collections of phonemes, the vowel phonemes in each collection or 'phoneme string' were analysed, and then the consonant phonemes in each phoneme string were analysed separately, and in each case a measure of similarity was constructed. Greater emphasis was given to the analysis of the consonant phonemes, as the consonant parts of words carry more information. Consideration was given during the process to the proximity of individual phonemes to each other; for example the 'v' sound was considered closer to the 'f' sound than, say, the 's' sound. An algorithm to measure lexical similarity of the misspelling against dictionary words was also constructed. The technique used was essentially equivalent to the algorithm given in (5), and referred to previously, with transposition of letters being assigned a minimal penalty. It was hoped that this would be particularly appropriate for the target client group, in view of the observed high frequency of letter scrambling by this group.

EVALUATION

The program was tested against four commercial spelling correctors, by running samples of text from five children known to have spelling difficulties through all programs, and observing the percentage of times when each program was able to offer the relevant correction for a misspelling. Initially a small sample, containing 100 misspellings was run through Speller and the four commercial programs, CorrectStar, PCWrite (both IBM programs) and WriteNow 2.0 and MacWrite 3.02 (both Macintosh programs). Speller performed somewhat better than all of these programs in this initial test. It was however decided to conduct a more detailed test on a sample of 709 misspellings using Speller, the IBM program that had attained the best results (CorrectStar) and the Macintosh program that had performed best (WriteNow 2.0). It was observed that WriteNow 2.0 appeared to operate by using edit operation analysis whereas CorrectStar appeared to use both edit operation analysis and some basic phonetic analysis. The results of this more detailed test were very favourable towards Speller. Not only did it find a significantly higher percentage of intended spellings (57% of correct spellings as the first prediction against 34% and 36%) than both commercial programs, but its failure rate was also much lower (14% against 45% and 55%). Versions of Speller have been introduced into the classroom environment for further field testing of the program. The reported response of both teachers and pupils to the system have been positive and a more detailed field evaluation of the program is planned. Evaluations of the program, in particular detection of unexpected behaviour of the matching algorithms, has been helped by a feature of the system, namely that all data generated during interactive use is logged on disk for future examination.

DISCUSSION

The results of the tests of the program suggested that a system had been developed which was much more appropriate for the special spelling requirements of the target group of users than commercially available spell-checking software. One of the major reasons for this would appear to be the phonetic matching algorithm: whilst many programs are unable to handle even the spelling of 'physics' as 'fysics' the Speller system will even offer 'physics' when spelt 'fzx'. Work is continuing to improve the matching algorithms where appropriate, and is now being extended to give the program the optional facility to query genuine spellings when the word in question is a homophone for another word.

CONCLUSION

A spelling aid has been designed for users with severe spelling disorders. This program appears to be significantly more helpful to this particular class of user than a conventional type of spelling corrector. The program is able to find the correct forms of the vast majority of the lexical and phonetic misspellings in the test data and many of those found would not be immediately obvious to a human when taken out of their context.

ACKNOWLEDGEMENTS

This work was supported by the Scottish Education Department, the Department of Trade and Industry, and the Training Agency (UK).

REFERENCES

1) Swiffin, A.L., Arnott, J.L., Pickering, J.A. and Newell, A.F., 'Adaptive and Predictive Techniques in a Communication Prosthesis', Augmentative and Alternative Communication 3 (4), December 1987, pp 181-191.

2) Damerau, F.J., 'A technique for computer detection and correction of spelling errors', Comm. ACM 7 (3), March 1964, pp 171-176.

3) Morgan, H.L.,'Spelling Correction in systems programs', Comm. ACM 13 (2), February 1970, pp 90-94.

4) Lowrance, R. and Wagner, R.A.,'An Extension of the String-to-String Correction Problem', J. ACM 22 (2), April 1975, pp 177-183.

5) Wagner, R.A. and Fischer, M.J., 'The String-to-String Correction Problem', J. ACM 21 (1), January 1974, pp 168-173.

6) Odell, M.K. and Russell, R.C.,U.S. Patent nos 1,261,167 (1918) and 1,435,663 (1922).

7) Davidson, L., 'Retrieval of Misspelled Names in an Airlines Passenger Record System', Comm. ACM 5 (3), March 1962, pp 169-171.

8) Elovitz, H.S., Johnson, R., McHugh, A. and Shore, J.E.,'Letter-to-Sound Rules for Automatic Translation of English Text to Phonetics', IEEE Transactions on Acoustics, Speech and Signal Processing 24 (6), December 1976, pp 446-459.

Andrew G. Wright,
Microcomputer Centre,
Dept. of Mathematics and Computer Science,
The University,
Dundee DD1 4HN,
Scotland, UK.

SYNTAX PAL - A SYSTEM TO IMPROVE THE SYNTAX OF THOSE WITH LANGUAGE DYSFUNCTION

8.5

Corinne Morris, Alan Newell, Lynda Booth & John Arnott
Microcomputer Centre, University of Dundee
Dundee, Scotland

ABSTRACT

Delayed or disordered expressive language often accompanies problems with spelling. We are developing a writing aid to help individuals with expressive language dysfunction, as an extension of PAL, a previously developed predictive spelling and typing aid. The enhanced system uses syntactic information to choose the predictions and will provide a postediting phase to remove any grammatical errors remaining in the text.

BACKGROUND

PAL (1), a predictive text input program, was originally developed as a typing aid for individuals with motor problems and was evaluated with schoolchildren in Tayside (2). It was found that many of these children also had spelling problems, and using the program helped their spelling. It became clear, as their spelling improved and their written output increased through using PAL, that some of the non-speaking users of PAL also had problems structuring their written language in a normal grammatical fashion.

The specific areas of syntactic difficulty vary from person to person in our study group. Some of the problems of the non-speakers appear to be related to their use of Blissymbol boards (3) to communicate. As Bishop (4) suggests, this communication system can hardly be responsible for their basic language dysfunction, and it is undoubtedly beneficial in many respects. However, it trains the non-speakers to use words in some non-standard ways; the impact of this is seen clearly in the writing of one of our non-speakers, and more subtly in the writing of the other two.

Two obvious areas where the communication board system has influenced grammar are use of tenses, and nuances of meaning. In Blissymbolics, the symbol for a tense is written together with the symbol for a particular verb to give the inflected verb. However, with a one-finger pointing system, the symbol for the tense must be pointed to separately from the symbol for the verb, and so is effectively treated as a separate word. This has carried over into one of our non-speakers' writing: he inserts the word "past" or "present" or "future" in the sentence rather than inflecting the verb.

On a communication board, there is also not much room for nuances of meaning. On our non-speakers' boards, one symbol is used for both "hear" and "listen"; another for "talk", "speak" and "say"; another for "like" and "enjoy" (although distinct symbols do exist, only the symbol for "like" is used on their boards). Both of our older non-speakers use "like" in contexts where "enjoy" would normally be used, a mistake made by only one of the speaking children in our study group. The oldest non-speaker in particular has numerous similar problems.

STATEMENT OF THE PROBLEM

Despite individual differences, and differences related to use of Bliss boards, syntactic errors made by our subject group of young people with language dysfunction are broadly similar; the exception is a child with Down's syndrome, whose writing is very difficult to decipher due to very bad spelling, and a tendency to wander from subject to subject and into long repetitions of a single word.

For those whose writing is more clear, the errors consist largely of omitted words or word endings, and to a lesser extent, insertion of superfluous words, incorrect use of words, use of words in the wrong order, and disagreements of number and tense. Examples of the sort of writing produced by two of our young people give a more concrete idea of these problems.

> *I in bed no well. I miss bus trip to Campeirdown to see the animals that sleep. Arlene went to see me. Gran going see Guy and Nicky.*
>
> *I went to my garys on struday I be playing card game. And sunday I went to the galaday it is dacaed. I boot fave book. And a tape case. And I went home to which the tv.*

APPROACH

We are attempting to address the syntactic aspects of language dysfunction using a similar strategy to that which we adopted for spelling problems. That is, we prompt the writer with syntactically correct words. The writer thus only needs to select words from a list of predictions rather than type the appropriate words in full.

The predictive system we have developed, "Syntax PAL", is an enhanced version of the predictive typing program PAL. Early work examining the use of syntax in a predictive system was reported in (5). This work investigated whether the use of syntax could improve keyboarding efficiency for people with motor dysfunction. The results indicated that a small increase in keyboarding efficiency could be achieved, and therefore syntactic parsing was not added to PAL at that time. It has now been added to help users with their syntax, rather than to increase keyboarding effeciency.

Our subject group of people with language dysfunction also have spelling problems, and therefore it was important to incorporate the functionality of PAL into the system. Also, we wanted to keep the user interface as simple and unobtrusive as possible. The interface therefore remains essentially the same as that of PAL.
A window of 5 predicted words follows the cursor around the screen, and the 5 predictions change as letters are added to or deleted from the word being typed. The major difference be-

tween PAL and Syntax PAL is the type of words predicted. PAL predicts frequent words and recently used words beginning with the prefix which has been typed, the only proviso being that certain function words are not allowed as predictions immediately after certain other function words (e.g. "the" will not be predicted after "the").

Syntax PAL also uses frequency and recency of words - but in addition it performs a complete syntactic parse of the partial sentence that has been typed so far, and only predicts words which could, according to the rules of English syntax, occur at this point. Like many parsers, its knowledge of English syntax is incomplete; but it is complete enough to be helpful to users with language dysfunction. Our earlier attempts to incorporate some syntactic information into PAL (5) had only considered two-word sequences, rather than complete sentences, and so could sometimes give syntactically inappropriate predictions. This new sentence-level approach eliminates this possibility.

DISCUSSION & IMPLICATIONS

It is likely that Syntax PAL will help more with some of the types of error mentioned above than others. For example, consider the sentence *It birthday Sheila*, for *It is Sheila's birthday*, which was written by one of our non-speakers. It contains three errors. The verb *is* has been omitted, as has the *'s* on the end of *Sheila*; also *Sheila* and *birthday* have been reversed.

A user of Syntax PAL would initially be given the five predictions *I, We, It, The, He*. *It* could be selected immediately with one keystroke. The predictions then change to *is, was, went, has, had*. The writer is thus reminded that *is* would be an appropriate word to follow *It*.

Assuming that *is* is selected, the next set of predictions will be *the, going, a, my, it*. There is nothing here to prompt the writer to begin writing *Sheila* rather than *birthday*, and once a wrong initial letter has been typed, *Sheila* will never be predicted. However, since *birthday* belongs to a word class which cannot, according to the limited grammar of Syntax PAL, come immediately after *It is*, this word will be given a low priority for predictions. The writer will thus have to type quite a few letters of *birthday* before it is predicted. Furthermore, when *birthday* is predicted it will appear in a special place in the prediction list, that is, after one or more suffixes. This place in the prediction list is reserved for words which the program has classified as ungrammatical in this context. Therefore the writer is given an indication that something is wrong.

Assume that the writer realizes what went wrong, deletes *birthday*, and begins to type *Sheila*. After two or three letters (depending on the exact content of the user dictionary) *Sheila's* will appear; *Sheila* will only appear later in that list, or in a later prediction list if the writer ignores *Sheila's* and continues to type. Both *It is Sheila* and *It is Sheila's* are grammatically correct; but *Sheila's* is predicted first, because the system's knowledge of grammar includes frequency statistics, and sentences with the structure of *It is Sheila's* appear more frequently than sentences like *It is Sheila* in the collection of children's writing used to teach the program its grammar. However, the system will gradually adapt to the specific style of an individual using it, and therefore the order of prediction of *Sheila* and *Sheila's* could conceivably change in time for a particular user. The grammar only adapts to the user's correct habits, and doesn't learn mistakes.

Prediction has offered some degree of help for each of the three mistakes in the above example, but is more immediately helpful for some of them than others. It is proposed that any mistakes which are made despite this help can be corrected in a postediting phase.

We are looking at two complementary ways of helping post-check for grammatical mistakes. One way is using a speech synthesizer to read back what has been written, as it has been found that non-speakers, in particular, can be helped to find their own mistakes by having their work read back to them. The second way is to use a syntax checker to find potential errors and suggest possible corrections, which the writer can choose from or reject. We are investigating how best to combine these two approaches to postediting.

Grammatical help can be provided in a postediting phase, but Syntax PAL aims to help the writer avoid making mistakes, rather than merely correcting them afterwards. In conjunction with postediting tools, it may be used as a language prosthesis for some users, or a language learning tool for others. We are currently evaluating Syntax PAL with a group of ten young people who have significant problems with written grammar, and further development will follow when its performance has been assessed.

ACKNOWLEDGEMENTS

Funding for this research was provided by the UK Training Agency, grant T89-23H-0180.

REFERENCES

1. Swiffin A, Arnott J, Pickering J, Newell A. *Adaptive and Predictive Techniques in a Communication Prosthesis*. Augmentative and Alternative Communication, vol 3 no 4 (1987), pp 181-191.

2. Booth L, Beattie W and Newell A. *I know what you mean*. Special Children 41 (Sept 1990), pp. 26-27.

3. MacDonald. *Teaching and using Blissymbolics*. Toronto: Blissymbolics Communication Institute, 1980.

4. Bishop D. *Language development in children with abnormal structure or function of the speech apparatus*. In: Language Development in Exceptional Circumstances. D. Bishop & K. Mogford, eds. Edinburgh: Churchill Livingstone, 1988, pp 221-238.

5. Swiffin A, Arnott J, Newell A. *The Use of Syntax in a Predictive Communication Aid for the Physically Handicapped*. RESNA '87 Proceedings, pp. 124-6.

Corinne Morris
Microcomputer Centre,
University of Dundee
Dundee, Scotland
DD1 4HN

PREDICTIVE RETRIEVAL OF CONVERSATIONAL NARRATIVES IN AN AUGMENTATIVE COMMUNICATION SYSTEM

8.6

Annalu Waller, Liz Broumley, Alan F. Newell & Norman Alm
Microcomputer Centre, Dept. of Mathematics and Computer Science,
University of Dundee, Scotland, UK.

ABSTRACT

Augmentative communication devices can enable non-speaking people to speak using phrases and sentences. Although conversational narratives play an important part in conversation, augmentative communicators seldom sequence sentences to form a narrative because of the physical effort involved. This paper reports on the progress of a system which provides an efficient storage and retrieval system which eliminates much of the effort required to tell stories [1].

INTRODUCTION

Current communication systems for non-speakers are based mainly on letters or words as the basic unit selected, although some use is also made of phrase and sentence storage. Yet, as Clarke and Clarke report [2]:

> "... hardly any of our day-to-day use of language stops after one sentence. People engage in conversations, stories, gossip and jokes that consist of a succession of sentences in a highly organized social activity."

Conversational narratives provide a communicative way of forming experience and relating past experience [3], and play an important part in an individual's social and educational development. Very few augmentative communicators, however, use their devices to engage in impromptu stories, gossip or jokes as the physical effort needed to produce the text is too great. Competent communicators will often ask friends to transmit longer communication, while others prepare stored texts before delivering lectures or attending meetings. But, the retrieval of large chunks of text within a conversation is rare because of encoding demands.

Instead of placing recall burdens on the user, our research attempts to release the user from having to remember what and where specific information is located by using semantic information about the user and the conversation environment. That enables non-speaking people to relate experiences, stories, etc. - a communication activity which, up to now, has been impossible.

A prototype system has been developed which contains the semantic information necessary to retrieve pre-stored narratives without the user having to do the equivalent of a database search, while trying to hold a conversation at the same time. Prediction of narrative texts and assisted searches for requested texts are performed on the basis of minimal input from the user and, once a conversational narrative has been selected, a narration procedure allows the user to step through the text at their own pace.

The organization and characteristics of conversational narratives were identified in a literature survey and were used to design the specifications for a narrative storage and retrieval system.

A prototype of this system, called "Prose" (Predictive Retrieval of Story Extracts), has been developed on an Apple Macintosh computer using Prolog. "Prose" is integrated with an existing conversation system, "TalksBack", thus providing a total communication system [4]. Like "Prose", "TalksBack" uses social and pragmatic knowledge to predict conversational utterances. Similarly, the algorithms it uses reduce the cognitive load on the user, and it enables the non-speaker to take a wide range of conversational rôles.

A DATABASE SYSTEM FOR CONVERSATIONAL NARRATIVES

Several techniques from the field of artificial intelligence have been used to simplify data retrieval and thus reduce the cognitive load and physical interaction associated with keyword searching and browsing. The database structure [1] has five distinct components:

A - the user interface (including story narration),

B - the retrieval system,

C - the current environment (i.e. identification of communication partner, conversational mood, subject),

D - the knowledge base, and

E - narrative texts.

Each narrative text has associated with it information which is used to describe the narrative. Figure 1 shows examples of the types of information which are used in association with the knowledge base.

The retrieval of a specific conversational item uses the current environment settings to find probable choices for the next conversational item. This sub-set of items will include narratives which are associated with the current and preceding environments in any way. The prediction algorithm (Figure 2) first eliminates those narratives with obvious clashes, e.g. the listener has heard, or is not permitted to hear a particular narrative.

When a sub-set of items has been identified, the current environment is matched with each item using a weighting procedure. Associated terms and concepts are identified using the knowledge base and weights are assigned accordingly. The closer the match, the higher the weight associated with the conversational item. These weighed items are ordered using frequency and date information to form the list of probable narratives offered to the user.

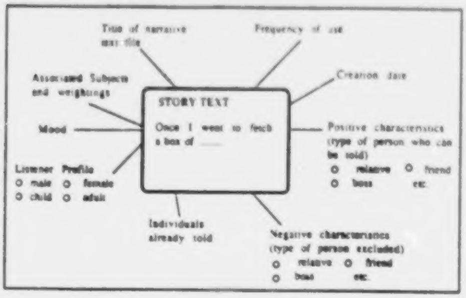

Title of narrative
text file
Frequency of use
Associated Subjects
and weightings
Creation date
STORY TEXT
Once I went to fetch
a box of ____
Mood
Positive characteristics
(type of person who can
be told)
○ relative ○ friend
○ boss etc
Listener Profile
○ male ○ female
○ child ○ adult
Individuals
already told
Negative characteristics
(type of person excluded)
○ relative ○ friend
○ boss etc.

FIGURE 1
Information stored with each narrative text

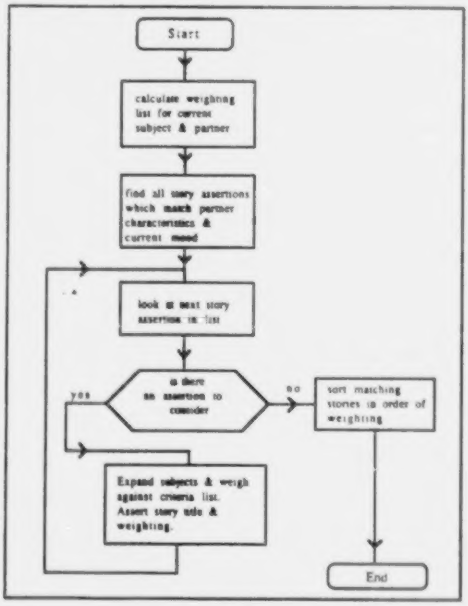

Start
calculate weighting
list for current
subject & partner
find all story assertions
which match partner
characteristics &
current mood
look at next story
assertion in list
is there
an assertion to
consider
yes
no
sort matching
stories in order of
weighting
Expand subjects & weigh
against criteria list.
Assert story title &
weighting.
End

FIGURE 2
Flowchart of prediction procedure

STORY NARRATION

Once a narrative has been selected, the user is able to narrate the story by selecting successive lines of text. These lines are highlighted automatically and can be spoken or skipped. Additional text can be added during the narration.

EVALUATION

User trials and evaluation of "Prose" will begin in January. Two non-speaking stroke clients, who have been using "TalksBack" for the past six months, will develop their own narrative databases. A series of conversations with family and strangers will be evaluated to see in what ways the availability of narrative retrieval affects the efficiency of their conversation. It is hypothesized that a narrative capability will enhance the communication potential of augmentative users.

FUTURE DEVELOPMENTS

Once the initial evaluations have been completed, we will develop the system further, incorporating ideas gained from practical use of the system. We will concentrate on areas such as story narration and pragmatics, and also the inter-relationship between the different levels of communication will be investigated further.

ACKNOWLEDGEMENTS

This work was supported by the South African Foundation for Research and Development, The University of Dundee Scholarship Fund, the TSB Foundation and the Digital Equipment Corporation.

REFERENCES

1) Waller, A., Alm, N., Newell, A.F., "Aided communication using semantically linked text modules", Proc. 13th RESNA, 1990.

2) Clarke, H.H. and Clarke, E.V., "Psychology and Language", Harcourt Brace Jovanovich Inc., New York, 1977.

3) Quasthoff, U.M., and Nikolaus, K., "What makes a good story? Towards the production of conversational narratives", in: Flammer, A. and Kintsch, W. (eds.), "Discourse Processing", Oxford: North-Holland Publishing Co., 1982, pp. 16-28.

4) Broumley, L., Cairns, A.Y. and Arnott, J.L., "Using artificial intelligence techniques in a personalized communication aid", Proc. 4th Biennial ISAAC Conference, Stockholm, Sweden, 1990.

Annalu Waller,
Microcomputer Centre,
Dept. of Mathematics and Computer Science,
The University,
Dundee DD1 4HN,
Scotland, UK.

BEST COPY AVAILABLE

Knowledge Representation Considerations for a Domain Independent Semantic Parser

Mark Jones, Patrick Demasco, Kathleen McCoy, & Christopher Pennington
Applied Science and Engineering Laboratories
University of Delaware/Alfred I. duPont Institute
Wilmington, Delaware USA

Abstract

We have previously presented the overall system design for the Compansion system and have discussed further enhancements to the parsing component that provides domain independent processing. In this paper, we discuss the knowledge representation scheme currently under development. The major improvements include a hierarchical-based lexicon representation, the use of case frame preferences for word role disambiguation, and improvements to the parsing logic that increase the overall system robustness.

Background

This work is part of an augmentative communication project being conducted at the Applied Science and Engineering Laboratories at the University of Delaware and the A.I. duPont Institute. The goal of this project is to increase the communication rate of physically disabled individuals via Natural Language Processing techniques.

We wish to take as input a compressed message (i.e., one containing mainly the content words of the desired utterance) from the disabled individual and generate a syntactically and semantically well-formed sentence. For a description of the Sentence Compansion system and the Semantic Parser's role in it see, (McCoy et al., 90). This paper builds on the previous work by describing recent insights into the knowledge representation scheme used by the semantic parser.

Statement of the Problem

The Semantic Parser (see also (Small &Rieger, 82)) is responsible for determining the semantic role being played by each input word. It must determine which word is the verb, what role each noun phrase plays with respect to the verb (e.g., actor, theme), and what modification relationships are present.

These inferences must be based on stored knowledge about individual words and possible word relationships. In our previous efforts, we utilized a a non-hierarchical word categorization scheme, and represented possible word relationships with relatively simple deterministic heuristics. While this approach proved satisfactory for relatively small vocabularies and simple sentence structures, it became necessary to consider substantial improvements to this aspect of the parser. In addition, we wanted to increase the robustness of the parser to accommodate ill-formed input.

Approach

Our approach is based on a Case Frame-based representation of sentence structure with word roles stored in hierarchical data structures. Heuristics employed to fill Case Roles represent uncertainty with preference scales. These preferences allow us to calculate a total confidence level for each potential parse. Finally enhancements to the parser logic allow us to infer the likely role of a word that is not explicitly stored in the lexicon.

Case Frame Representation

The output of the parser is in the form of Case Frames (Fillmore, 77). The main idea behind case frames is that in a sentence there is a fixed number of roles that objects can play with respect to the main verb. Given the input: [John break hammer], the parser will return the semantic parse below.

```
((43 DECL
     (VERB (LEX BREAK))
     (AGEXP (LEX JOHN))
     (THEME (LEX HAMMER))
     (TENSE PRES)))
```

This parse is consistent with the sentence, "John breaks the hammer." The first line gives a confidence value for the parse, and says that this is a declarative sentence. The second line states that the main verb of the sentence is *break*. The third line states that the AGEXP (doer) of the break action is *John*. The next line says that what is being broken is a *hammer*.

Given the input: [John tell Mary Joke Sue], the parser will return (among others) the semantic parse below.

```
(71 DECL
     (VERB (LEX TELL))
     (AGEXP (LEX JOHN))
     (THEME (LEX JOKE))
     (GOAL (LEX MARY))
     (BENEF (LEX SUE))
     (TENSE PRES))
```

This parse is consistent with the sentence, "John tells a joke to Mary for Sue." There are a few new cases that should be explained. Note that the THEME is *joke* and not *Mary*; *joke* is what is being told. *Mary* is the receiver, the GOAL. Finally, the act is done for *Sue*; she is the BENEFiciary.

Knowledge Representation

The knowledge used by the parser must be as great as possible because it cannot rely on syntactic information. Also, this knowledge must be domain independent. The parser utilizes several knowledge hierarchies of which two are particularly important. The object hierarchy captures generalizations about nouns. The verb hierarchy captures generalizations about verbs.The main verb of the sentence is key in predicting the semantic structure of the sentence. The layout of the verb hierarchy is motivated by work in systemic grammar (Halliday85). There are two general types of heuristics: Those that are semantic in nature, and those that are more idiosyncratic to the verb, more syntactic in nature.

Idiosyncratic Case Constraints

The idiosyncratic case constraints are called idiosyncratic because they are attached to individual verbs, rather than inherited. There are two key properties that can be associated with each verb. They are *Mandatory* and *Forbidden*. For example, the verb *hit* requires that the THEME be filled. The *mandatory* feature allows this to be represented. On the other hand, *hit* cannot accommodate a GOAL. This can also be represented in the system. This relates to traditional linguistics. Typically intransitive verbs forbid the filling of the THEME case: *die* cannot have a theme Words other than bi-transitives typically forbid filling the goal case: *give* can have a goal. The most common situation, that of the verb neither forbidding nor requiring a particular case, is represented by the absence of either feature.

Semantic Case Preferences

The semantic preferences differ from the syntactic predictions in a number of ways. First, these semantic preferences are not as definite, they are much fuzzier in nature, thus the term *preference*. These preferences are the basis for the heuristic values given to the output interpretations. Second, unlike the constraints, these semantic preferences are general enough to be inherited down a hierarchy of verbs. Third, these semantic preferences are closely tied to the object hierarchy. The case constraints have no interest in how the object knowledge base is structured.

Semantic preferences rely on a numeric scale ranging from 1 for low preference to 4 for high preference. In this scale, 1 and 4 are for special cases. 4 signifies that the binding is exceptionally appropriate. 1 signifies that the binding is only appropriate in special cases. For normal situations, the ratings of 2 and 3 are used. At this point, this granularity seems appropriate for our level of inferencing.

Case Importance Preference - This preference represents how important it is to fill a particular case in the frame. This is much more flexible than mandatory and forbidden which were described previously. For example, with material verbs such as *kick*, it seems much more likely that the role of THEME will be filled than that of BENEFiciary. To represent this, a higher value (3 on the 1 to 4 scale) is given as the preference of filling the THEME case, while a lower value (1) is given as the preference for filling the BENEFiciary case.

Case Filler Preference - This preference is directly related to the object hierarchy. Here, what kinds of objects should be playing the role is represented, this along with a preference of how reasonable such a binding seems. For example, the preference for filling the BENEFiciary case for most verbs is: ((human 3) (organizat 2) (animate 2)). This means that 3 points (again on the 1 to 4 scale) are given for binding a human in the given role. A binding of organizations, such as the A.C.L.U., or animate objects yield two points. This specification may seem ambiguous, is not any human also animate? True, the solution used in this system is that if a binding can achieve more than one score, the highest of the scores is used. Also note that a list such as the one just given is considered exclusive. In this example, it means that any verb following the stated pattern for BENEFiciaries will not allow objects that do not have as ancestors one of the three types given. A chair (inanimate object) would not be considered as a BENEFiciary.

The inheritance mechanism for the case importance and the case filler preferences is rather simple. Those preferences stated by the highest ancestors of the verb hold preferences that are reasonable in general. If conflicting information is given by more specific (lower) ancestor of the verb, the more specific information will be recognized.

Higher-Order Case Preferences - The mechanisms for Fill-Case and the Fill-Case-with-what preferences are limited in scope only to one role at a time (e.g., BENEFiciary). The Higher-Order Preferences fill the need for some more unifying heuristics With this power we can represent the following: If a non-human animate (e.g., dog) is the AGENT of a material process, it is quite unlikely that an instrument is being used.

Unknown Words

The power of this knowledge representation scheme provides robustness in parsing ability. The system is able to make some sense out of unknown words present in the input stream. If the parser knows the main verb of the sentence it can infer the role of the unknown word and the type of object that is represented. The parser assumes that an unknown word is an object. It then creates multiple senses of the unknown word; one sense for place, tool, food, etc. These senses are chosen to cover the range of objects yet not be too specific. Because multiple word senses are treated as mutually exclusive, it tries each sense separately. The heuristic ratings allow the interpretation(s) with the best word sense to rise to the top, and a moderately intelligent guess of the unknown word is achieved. The information inferred about the unknown word can be passed on to and referenced by the processes that follow the semantic parser. The table below lists several examples followed by the case that the unknown word (**XXX**) is interpreted to fill, and the type of object in the object hierarchy that the object is interpreted to be.

[John break window XXX]	INSTR	tool
[John eat XXX fork]	THEME	ingestible
[John eat pizza XXX]	INSTR	tool
[John tell XXX Mary]	THEME	abstract
[John go XXX]	LOC	place
[XXX carry paper]	AGEXP	animate and ergative-object (tie)

Implications

This approach takes advantage of several important generalizations. First, the object and verb hierarchies capture needed generalizations. Also, the preferences are distributed among the verbs in a motivated manner. This approach lends elegance to the system, and makes it easier to enhance.

Distinctions between the knowledge have been well placed. First, separating the idiosyncratic constraints (what roles must and must not be filled) from the preferences (what roles should be filled, and with what) is useful. This is key to the elegance of the knowledge hierarchies, because such behaviors cut across different dimensions. The notion of transitivity was used to explain the more syntactic knowledge. Such knowledge as transitivity clearly cuts along a different dimension than that of meaning. For example, the parser encodes the words *eat* and *swallow* as semantically equivalent. However, swallow cannot typically have an instrument, while eat may.

Previous approaches to representing such knowledge have not distinguished between that captured in case importance and case filler preferences. Without this distinction, statements such as those of case importance cannot be made. Recall, that for many material verbs, such as hit, filling the THEME role is very important. But without such information, the parser would mistakenly consider Mary in [John hit Mary] a BENEFiciary, because, other things being equal, people are highly correlated to the BENEFiciary role.

Another major advantage of this system is its use of heuristics. Not only can the system handle [John break hammer], but also [John break hammer window], where hammer now plays a different role (Instrument). Through its robust heuristics, it can recognize the preferred interpretation of this message.

Discussion

Although the parser has been radically changed in the last year, it already captures the functionality of the previous system, including inferring agents and verbs in some situations.

With these theoretical improvements in the semantic parser, we come closer to our goal of making available an augmentative communication system which takes advantage of the power of research in the field of Natural Language Processing.

Acknowledgments

This work is supported by Grant Number H133E80015 from the National Institute on Disability and Rehabilitation Research. Additional support has been provided by the Nemours Foundation.

References

C.J. Fillmore.The case for case reopened. In P. Cole and J.M. Sadock, editors, *Syntax and Semantics VIII Grammatical Relations*, pages 59-81, Academic Press, New York, 1977.

Halliday M. A. K. *An Introduction to Functional Grammar*. Edward Arnold, London England, 1985

K. McCoy, P. Demasco, M. Jones, C. Pennington, and C. Rowe. A Domain Independent Semantic Parser For Compansion. In *Proceedings of the 13th Annual RESNA conference*, pages 187-188, RESNA, Washington, DC., June 1990.

S. Small and C. Rieger. Parsing and comprehending with word experts (a theory and its realization). In Wendy G. Lehnert and Martin H. Ringle, Editors, *Strategies for Natural Language Processing*, 1982.

Contact

Mark Jones
Applied Science and Engineering Laboratories
A.I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
Email: jones@udel.edu

8.8

VOCABULARY SELECTION FOR INTELLIGENT PARSING IN AN AAC SYSTEM FOR APHASICS

Bruce R. Baker, Semantic Compaction Systems
Kathleen McCoy, University of Delaware / A.I. DuPont Institute
Sheela Stuart, University of Nebraska
Eric H. Nyberg 3rd, Carnegie Mellon University / Semantic Compactions

Abstract

A communication aid which incorporates a parser with limited intelligence is under development, and is intended help individuals with aphasia to communicate. There are three important issues that must be addressed in the design of such a system: language representation (how to represent words, phrases, and topics in a way accessible to a person with aphasia), vocabulary selection (which words, etc., to include in the system), and syntactic and pragmatic defaults (what kind of sentence structures should be included in the parser's generative capacities). This paper explores a methodology for designing an intelligent communication device that pays particular attention to these issues. Much of what is discussed should also be useful for designing conventional communication systems as well.

Background

The term *aphasia* refers to an acquired disturbance of communication resulting from damage to areas of the brain that are responsible for language function. Aphasia varies in terms of severity and predominant symptoms, but for most people, aphasia involves problems in talking, listening, reading, writing, and gesturing. Other motor and sensory problems, such as dysarthria and apraxia, frequently coexist with aphasia (Katz, 1990, p. 167). Defining aphasia in terms of general versus specific language impairment leads to controversy about classifying persons with aphasia into various types.

Those who require classification of specific impairment (Rosenbek, LaPoint, & Wertz, 1989; Goodglass & Kaplan, 1972; Kertesz, 1979) divide aphasic patients into groups according to salient symptoms. There are numerous classification systems. Some of the most popular systems reflect universally observed symptomatic differences. Some people with aphasia talk a lot, while others speak very little, leading to the binary classification of *fluent* versus *nonfluent* aphasia (Goodglass & Kaplan, 1983b). Some aphasic patients have predominant problems in understanding and others have predominant problems in word finding. Thus classification may be made on these bases: *expressive-receptive* aphasia (Weisenburg & McBride, 1935) versus taxonomic categorization of aphasia (Kertesz, 1979).

Supporters of the generalist approach (Darley, 1982; Schuell, Jenkins & Jimenez-Pabon, 1964) resist categorization, and maintain that patients suffering from aphasia have in common symptoms which can be described as impairment of the capacity for interpretation and formulation of language symbols. Such symptoms include multimodal loss or reduction in efficiency of the ability to decode and encode conventional meaningful linguistic elements (such as morphemes and larger syntactic units), reduced availability of vocabulary, reduced efficiency in application of syntactic rules, reduced auditory retention span, and impaired efficiency in input and output channel selection (Darley, 1982).

Augmentative/alternative communication (AAC) systems which would be useful for people with aphasia must incorporate features which address both the diversity and the commonality of this population. For example, it may seem as though a system which provides speech output for pre-stored sentences might be quite successful for an individual with aphasia who is unable to formulate and articulate his or her own sentences. However, a sentence vocabulary can be difficult to process for many individuals with aphasia, because they may have difficulty placing a sentence lexicon into working memory. Pictorial rather than orthographic indices have been shown to improve the ability of some aphasic individuals to access vocabulary (Steele, 1987), yet a system making use of single-meaning pictures requires a picture for each vocabulary item, making it impractical for all but the most limited vocabularies. The generative power of a word-based system has been deemed beyond the reach of many individuals with aphasia owing to their problems with syntax and lexical access, although some systems with elaborate hierarchical indices have been proposed (Steele, 1987).

Identifying the major needs of a broad range of individuals with aphasia would seem to supply a direction for AAC application of technology. Kraat (1990) states that early research and clinical reports suggest that AAC techniques might have three important roles in aphasia treatment:

> "First, as a compensatory or alternate means of communication in lieu of spoken language, secondly, as a facilitation technique for the re-acquisition of spoken language skills; and thirdly, as an associative 'link' to enable spoken language skills to take place." (p. 322)

The task of this paper is to report recent efforts and progress toward providing a means of accomplishing the first role. A new type of electronic communication device geared toward speech output for this population is currently under development. The hope is that the device will help people with aphasia to overcome both the lexical access problem (by providing an appropriate interface for word selection) and the syntactic production problem (by providing an intelligent parser that can generate well-formed sentences from an underspecified input).

Statement of the Problem

The first problem that arises in the design of a communication aid for people with aphasia is the representation of vocabulary. It is a challenge to represent a large vocabulary in a transparent manner for individuals experiencing substantial lexical access problems. The iconic technique under exploration may provide individuals with a cognitively syntonic representation of several hundred words.

Even with a transparent language representation, the size of the vocabulary that such an individual can access is necessarily limited. The second problem, thus, is in selecting an appropriate vocabulary. The vocabulary must be large enough for gratifying interaction, but small enough so that its access does not overwhelm an individual with aphasia.

The goal is to provide an individual who has less than complete syntax with the ability to create well-formed sentences by entering just a string of content words. Thus, the third problem that must be addressed is configuring the syntactic prosthesis. The intelligent parser must be able to give an interpretation that is complete yet appropriate to the user's style and needs. It is certainly possible to decide in advance that certain more likely interpretations shall be made for given types of sentences, but the system must have a mechanism for incorporating the default interpretations that best fit the particular individual.

A large number of individuals with aphasia experience their lesions in the 7th or 8th decade of life. As adults reach their 60s, 70s and 80s, there are changes in many aspects of their lives. One of the areas that reflects this change is the way people of this age take part in conversation. Older persons are listened to in ways that are different from younger persons. Information expected from older persons is, at least in part, determined by the age-grade role. The type of request for information from them is often performed as though the aged person was a repository of cultural lore. It is hypothesized that this role, along with inherent biological changes, may cause older persons to recall and recode into a story-like mode, which often reflects the extensive elaboration of memory information and serves to make it highly digestible for the listener (Mergler & Goldstein, 1983).

The foregoing paragraph serves to illustrate the notion that elderly individuals, who comprise the majority of individuals with aphasia, have quite different communication needs from those of the general population. This certainly has an impact on the size and content of an effective vocabulary for such individuals; the story-telling mode of communication requires a rich vocabulary which may intersect with, but is not limited to, the everyday vocabulary most often associated with electronic communication aids. In addition, the types of sentences favored by these individuals can impact on the type of syntactic processing that should be available in a successful syntactic prosthesis. For example, the use of anaphora, ellipsis, and conjunction decline with the age of the storyteller and with the complexity of the narratives (Kemper, Rash, Kynette and Norman, 1990).

Approach

Language Representation

A common problem experienced by people with aphasia is the failure to access the lexical items which correctly express the semantic meaning the individual wishes to communicate. An iconic interface may be helpful to such individuals because it may be easier to identify pictures or *icons* which represent the meaning they wish to express. In order to make this reasonable in terms of the physical layout of an interface, it is not enough to use single-meaning key actuations, since this would require an interface with 300 keys to represent 300 words. Instead, the project utilizes an iconic representation approach requiring two key actuations for each selection, which can therefore represent 300 words using far fewer keys. Consider, for example, the selection of the noun *sleeve*. The first actuation would be of a key representing the semantic category of the desired noun (e.g., CLOTHING). The second key in the sequence would be selected from a set of more complicated icons, implicitly representing items from several semantic categories. The multiple meanings associated with the second icon would be disambiguated based on the first selection. For example, if CLOTHING has been selected, then an icon picturing a POLICEMAN might result in the selection of the noun *hat*, while the selection of an ARM icon illustrating an arm holding an ice cream cone might result in the selection of the noun *sleeve*. Note that the same icons can trigger different nouns if a different category has been chosen, e.g., selecting the ARM icon when the FOOD icon has been selected might give us *ice cream*.

The utility of such a representational scheme is being developed through interactions with able-minded individuals in their 7th and 8th decades, as a prelude to testing on individuals with aphasia. We hypothesize that this representation technique will support lexical access of several hundred lexical items for this population, using a relatively small number of keys.

Vocabulary Selection

Our goal is not merely to provide an unstructured "word list" for this set of clients; rather, we feel that the following steps are necessary in the creation of a complete model of the client vocabulary:

- *Corpus Acquisition.* Using appropriate data collection techniques, a large representative corpus is gathered.
- *Language Analysis.* The corpus is analyzed in order to answer the following questions about the language model:
  1. What words and classes of words are used?
  2. What syntactic structures are commonly used?
  3. What semantic concepts underly the communication?
  4. What pragmatic goals are evidenced in the communication?
- *Language Model.* The results of language analysis are compiled into the lexicon, syntactic rules, and semantic concepts needed to design and implement the communication aid.

Syntactic Defaults

The job of the intelligent parsing component in a communication aid is to determine which of the available syntactic patterns best fits a particular input given by the individual with aphasia. The knowledge required to perform this task successfully results from the construction of a language model for a particular client group (Fristoe and Lloyd, 1980). Construction of the language model will reveal patterned relationships between what the individual wishes to express and the syntactic patterns commonly used by non-aphasic individuals in similar life circumstances.

Once the client has selected a sequence of icons that express the intended communication, the parser must "fill in the gaps" left behind owing to a lack of syntactic knowledge on the part of the client. Some individuals with language loss are prone to lapses in correct word order and the omission of function words, such as determiners and prepositions. For example, the user might key in the icon sequences for the words `TABLE CUP PUT` when the intended communication is *Put the cup on the table.* In this case, the intelligent parser must determine that `CUP` is the object of `PUT`, and that `TABLE` is the locative of `PUT`, and reorder the words appropriately. The parser must also add any missing determiners (like *the*) and prepositions (like *on*).

Implications

Corpus Acquisition. Cerebro-vascular accidents (CVAs) causing aphasia often strike individuals in their 7th and 8th decades (60's and 70's). Stuart and Beukelman (in press) examine the topics and lexica used by 5 non-aphasic individuals in this age group. While these individuals are not aphasic, it is reasonable to expect that their vocabulary and syntax needs are similar to those of aphasics in this age group (Holland, 1975). Beukelman and Stuart's data collection methodology has resulted in the recording of a large amount of previously unavailable data concerning the vocabulary and topics prevalent in an age group commonly affected by aphasia. These data and the language corpora resulting from Stuart's subsequent work (Stuart, forthcoming) form the basis of the vocabulary being developed.

Language Analysis. The analysis of the acquired corpus involves morphological and syntactic analysis of each sentence to determine not only the actual word forms present, but also the underlying lexical form and inherent meaning of each word. For example, the verb *throw* can appear in various surface forms. If a system fails to perform morphological analysis, it will be unable to determine that *throws* and *threw* are both forms of the same verb. In addition, if we fail to perform syntactic and semantic analysis, we will conflate the occurrence of a single form of *throw* in sentences like *John threw up* and *John threw the ball*. The key point is that the same surface form can be used to indicate different meanings, depending on the surrounding words (i.e., syntactic structure). It should be noted that syntax is sufficiently rich to render ineffectual the use of simple two-word co-occurrences; for example, in *John threw his hands up*, an entire noun phrase is interposed between the verb and its particle. In this case, the verb and its particle can only be related through a more complete syntactic analysis. Without this type of detailed analysis, broad classes of words (such as phrasal verbs, non-neighboring collocations, etc.) cannot be distinguished on the basis of key-word analysis only. It is also difficult to appreciate the pragmatic communication goals of the client group unless this type of analysis is performed, since the overall desire expressed by a particular communication act depends quite heavily on its syntax and semantics.

Language Model. Once the corpus has been analyzed, a language model is constructed that includes not only the selected vocabulary, but also a set of syntactic constructions, pragmatic goals, and semantic concepts that must be present to support communication by the client group. This is necessary to support the subsequent design and development of a communication aid for the particular client group, since not only the vocabulary itself but also the syntax, semantics, and pragmatics must also be encoded in the device (McCoy, et al., 1990).

Discussion

The use of intelligent parsing in augmentative communication has been a distant dream for many years. The actual development of such a system is now at hand. Older adults with aphasia have been selected as its first target population, because the needs of this community are underserved, and the potential benefits of intelligent parsing are great. A substantial corpus, reflecting the actual speech and language use of this population has been gathered and is now the object of attention by computational linguists and speech pathologists in 3 major centers of research.

Some form of intelligent parsing may hold great promise in the design of AAC systems for aphasic individuals. The strengths of intelligent parsing (filling in missing words and re-ordering scrambled input) complement the difficulties of individuals with reduced language function. In addition, an intelligent parsing system that utilizes an iconic interface can make that capability available in a pictorial form that might be easier for aphasics to access, thus addressing the important problem of lexical access faced by individuals with aphasia.

To make intelligent parsing successful for a broad range of clients, we must envision not a single system with a single vocabulary, but several systems with vocabularies tailored for particular client groups and indeed particular clients. The effectiveness of intelligent parsing techniques can only be as effective as the the amount of care taken to acquire and support the vocabulary and language model required by the particular client or client group. Note we are not suggesting that our initial corpora vocabulary will in itself be sufficient for all clients. Indeed, the content of individual "stories" must be client specific, and will draw on both the common vocabulary and a vocabulary specific to the particular client. The client-specific vocabulary must also be acquired and made available in the communication aid. However, analysis of the collected corpus should provide us with a set of contextual guidelines which will make it much easier to query close family members for vocabulary content specific to a given individual in specific communication situations.

Acknowledgements

This work is supported in part by Grant #H133E80015 from the National Institute on Disability and Rehabilitation Research. Support was also provided by the Nemours Foundation.

References

Darley, F. (1982). *Aphasia.* Philadelphia: W. B. Saunders.

Fristoe, M. & L. Lloyd (1980). Planning an initial expressive sign lexicon for persons with severe communication impairment. *Journal of Speech and Hearing Disorders*, 45:170-180.

Goodenough-Trepagnier, C. (1989) VIC performance: Effect of grammatical category. *Proceedings* RESNA 12th Annual Conference, New Orleans, Louisiana, pp. 143-144.

Goodglass, H. & Kaplan, E. (1972). *The assessment of aphasia and related disorders.* Philadelphia: Lea & Febiger.

Goodglass, H. & Kaplan, E. (1983b). *The assessment of aphasia and related disorders (2nd ed.).* Philadelphia: Lea & Febiger.

Holland, A. (1975) Language therapy for children: Some thoughts on context and content, *Journal of Speech and Hearing Research*, 40: 514-523.

Katz, R.C. (1990) Microcomputer applications in research on treatment of aphasia. In E. Cherow (Ed.), Proceedings of the Research Symposium on Communication Science and Disorders and Aging, (pp. 167-176). Rockville, Maryland, American Speech-Language-Hearing Association.

Kemper, F., Rash, S., Kynette, D., and Norman, S. (1990) Telling stories: the structure of adult's narratives, *European Journal of Cognitive Psychology*, Vol. 2, No.3, p. 205-228.

Kertesz, A. (1979). *Aphasia and associated disorders: Taxonomy, localization, and recovery.* New York: Grune & Stratton.

Kraat, A.W. (1990). Augmentative and alternative communication: does it have a future in aphasia rehabilitation? *Aphasiology*, 4 (4), 321-338.

McCoy, K., E. Nyberg and B. Baker (1990). Intelligent AAC Systems: What Can Be Done Now, *Proceedings* RESNA 13th Annual Conference, Washington, DC, June 19.

Mergler, N. and M. Goldstein (1983). Why are there old people? *Human Development*, 26:72-90.

Rosenbek, J., LaPointe, L., & Wertz, R. (1989) *Aphasia: a clinical approach*, Austin, Texas: Pro. ed.

Schuell, H., Jenkins, J., & Jimenez-Pabon, E. (1964). *Aphasia in adults: Diagnosis, prognosis, and treatment.* New York: Hoeber Medical Division, Harper & Row Publishers.

Steele, R., M. Weinrich, M. Kleczewska, G. Carlson, and R. Wertz (1987). Evaluating performance of severely aphasic patients on a computer-aided visual communication system. In R. H. Brookshire, ed., *Clinical Aphasiology*, Minneapolis: BRK Publishers.

Stuart, S. (forthcoming). PhD dissertation (in progress), University of Nebraska, Lincoln.

Weisenberg, T. & McBride, K. (1935). *Aphasia: A clinical and psychological study.* New York: Commonwealth Fund.

Bruce R. Baker
Semantic Compaction Systems
801 McNeilly Road
Pittsburgh, PA 15226

BEST COPY AVAILABLE

The Effects of Physical Ability on the Working Memory Requirements of Computer Input Devices

Mary Klein, MSIE and Don Malzahn, Ph.D.
Industrial Engineering Department
Rehabilitation Engineering Center
The Wichita State University
Wichita, Kansas

ABSTRACT

Three computer input devices were used to determine if differences in physical ability result in differences in mental workload as measured by working memory capacity. The three devices were a voice input system, trackball, and two-degree-of-freedom keyboard with headstick. Subjects with cerebral palsy used the three devices to perform a dual-task and their results were compared with those obtained from a sample of non-disabled subjects. The dual-task consisted of transcribing a word while remembering a number. Working memory capacity was defined as the maximum number of digits remembered correctly.

The values for working memory capacity were normalized using the results from the Digit Span test from Wechsler's Adult Intelligence Scale. Results showed no significant difference in normalized memory capacities between the two groups when using the different input devices. However, there were significant differences between devices and trials for both groups.

INTRODUCTION

Recent legislation has made it mandatory that all government office equipment, including computers, be accessible for persons with disabilities. As computers gain broader acceptance in the workplace, a wide variety of computer input devices are being developed. These devices may require different mixes of physical and mental abilities. These devices may or may not be effective for individuals with disabilities.

Researchers have concentrated on physical performance aspects, such as keystroke rate and keystroke accuracy, when evaluating input devices. This is also the situation in the development of augmentative computer input systems for persons with disabilities (Rosen and Goodenough-Trepagnier,1989). However, barriers to computer accessibility may be presented not only by physical and sensory components of computer systems but by their cognitive requirements as well (Cress & Goltz, 1989).

In this study, an attempt was made to quantify the relative cognitive load of three non-standard input devices by determining their effect on working memory capacity. These values were used along with scores from a Digit Span test to obtain individually normalized assessments of memory capacity. The objective was to determine whether differences in physical ability result in significantly different values for normalized memory capacity. A higher working memory capacity for a device indicates that more mental effort is required for its use. Because of a reduced level of physical dexterity, the group of subjects with cerebral palsy were hypothesized to require greater mental effort to use a particular device.

METHODS

Subjects

Five individuals with cerebral palsy and five individuals with no physical disabilities participated as subjects in this study. Both groups consisted of four males and one female.

Apparatus

The input devices used were as follows: BUG Voice Command System (Command Corp., Inc.), FastTRAP Trackball (MicroSpeed, Inc.) with a screen displayed keyboard (Freeboard from Pointer Systems), and two-degree-of-freedom keyboard with headstick (Johnson, 1986). All keyboards were presented with the letters arranged in an alphabetic order. The voice system required alphabetic input with a military alphabet.

Procedure

Working memory capacity was measured using a dual-task computer program written in Quick Basic (Turner and Engle, 1989). Each subject was presented with a word-number pair. The primary task involved inputting the word that appeared on the computer monitor using the different input devices. The words were selected randomly from a list of 204 commonly used words which were 4-6 letters in length. The secondary task was to remember the number that appeared next to the word. These numbers were randomly generated between 1 and 9. If the subject input the number correctly, the next set consisted of two word-number pairs. Each time the subject input the appropriate numbers in the correct sequence, the number of word-number pairs increased by one. If the subject made a mistake, the program would retreat to the previous set size. Working memory capacity was defined as the maximum number of digits which could be recalled correctly.

Each subject had a minimum of three trials on each device. Testing continued until the value for working memory capacity for the current trial was equal to or less than the value from the previous trial. Once a subject completed testing on all three devices, he or she was given the Digit Span test from Wechsler's Adult Intelligence Scale. This Digit Span test was a measure of memory capacity without a secondary task or device load. By dividing each subject's values for working memory capacity on each device by their Digit Span test score, an individual specific normalized value for memory capacity was obtained.

RESULTS

An analysis of variance (ANOVA) was performed. The results showed no significant difference in NMC (normalized memory capacities) between the two groups. However, the device and trial factors were both significant. Post-hoc analysis using Duncan's multiple range test ($\alpha = 0.05$) showed no significant difference between the two-degree-of-freedom keyboard and the trackball. The value for the voice input system was significantly lower (Figures 1 and 2). Duncan's multiple range test ($\alpha = 0.05$) also showed no significant difference between trials 1 and 2, however trial 3 was significantly higher (Figures 3 and 4).

ANOVA Summary for NMC Values

Source	SS	MS	dF	F
Model	4.465	0.179	25	8.52
Error	1.341	0.021	64	
Total	5.806			

Source	SS	dF	F	pr>F
BETWEEN GROUP				
Group	0.003	1	0.01	0.9336
Error(Sub(Grp))	3.580	8		
WITHIN GROUP				
Device	0.321	2	7.65	0.0011
Grp*Dev	0.068	2	1.62	0.2062
Trial	0.457	2	10.91	0.0001
Dev*Trl	0.010	4	0.37	0.8856
Grp*Trl	0.007	2	0.17	0.6447
G*D*T	0.030	8	0.18	0.7933

Group:	Able-bodied vs. Cerebral Palsy population
Sub:	Subjects (10)
Device:	Input Devices (3)
Trial:	Repetitions (3)

Duncan's Multiple Range Test Results for NMC

Factor	Mean	Grouping
Device		
TDOF KB	0.573	A
Trackball	0.542	A
Voice Input	0.433	B
Trial		
3	0.608	A
2	0.505	B
1	0.435	B

Other measures of input device performance indicated significant differences in the expected directions. Similar analysis of variance was performed on other dependent measures of Keystroke Efficiency and Keystroke Rate. Keystroke Efficiency (the ratio of correct keystrokes to total keystrokes) was significantly higher for subjects without disabilities than for subjects with cerebral palsy. Devices also differed significantly on Keystroke Efficiency for both groups. Keystroke Rate (keystrokes per second) was significantly higher for subjects without disabilities than subjects with cerebral palsy. Devices also differed significantly on Keystroke Rate for both groups. Neither Keystroke Efficiency or Keystroke Rate differed significantly among trials.

CONCLUSIONS

Differences in physical ability did not result in significant group differences in normalized memory capacity. Therefore, a lower level of physical ability did not imply a higher cognitive load for task performance. The Normalized Memory Capacity was significantly affected by device selection. Different

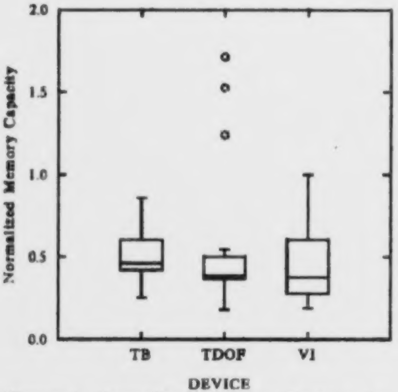


Figure 1. Normalized Memory Capacity for subjects with Cerebral Palsy as a function of Input Device.

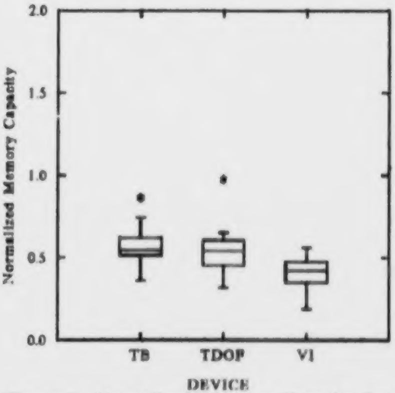


Figure 2. Normalized Memory Capacity for Non-Disabled Subjects as a function of Input Device.

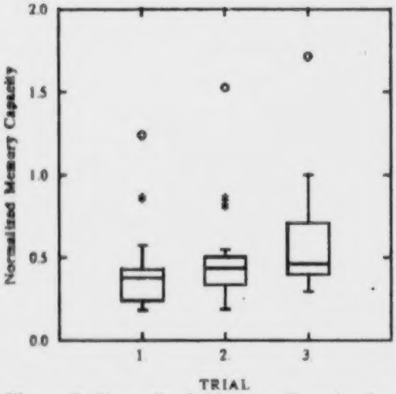


Figure 3. Normalized Memory Capacity for subjects with Cerebral Palsy as a function of Trials.

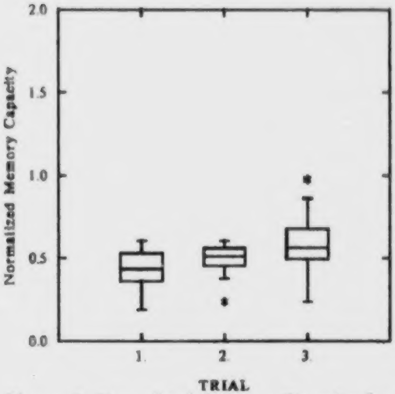


Figure 4. Normalized Memory Capacity for Non-Disabled Subjects as a function of Trial.

devices imposed different levels of mental workload. This measure was also significantly affected by repetition showing an improvement with experience.

One subject with cerebral palsy performed significantly better with the TDOF Device on all three trials than any other subject. This is graphically demonstrated in Figures 1 and 3. Although the group with cerebral palsy did not differ significantly from nondisabled group, this one subject showed a significantly increased Normalized Memory Capacity when using the TDOF Device.

These findings must be contrasted with the results indicating that differences in physical ability do produce significant differences in Keystroke Efficiency and Keystroke Rate. It is also relevant that these standard measures of device performance did not improve with repeated trials, while there were significant differences in Normalized Memory Capacity with practice. The general conclusion is that the cognitive load required by a computer input device can have a significant effect on task performance, but the effect on performance is independent of the level of physical ability of the user.

REFERENCES

Cress, C. & Goltz, C. (1989). Cognitive Factors Affecting Accessibility of Computers and Electronic Devices. RESNA 12th Annual Conference, 25-26.

Johnson, E.L. (1986). A 2DOF headstick actuated IBM PC compatible keyboard. Proceedings of the IEEE 1986 Region 5 Conference, 73-77.

Rosen, M.J. and Goodenough-Trepagnier, C. (1989). The Tufts-MIT Prescription Guide: Assessment of Users to Predict the Suitability of Augmentative Communication Devices. Assistive Technology, 1(3): 51-61.

Turner, M.L. and Engle, R.W. (1989). Is Working Memory Task Dependent? Journal of Memory and Language, 28, 127-154.

ACKNOWLEDGEMENT

This research was conducted under the sponsorship of NIDRR Grant Number H133E80002.

ADDRESS:
Department of Industrial Eng.
Wichita State University
Campus Box 35
Wichita, KS 67208

9.2

An Interactive Tool for Visualizing the Biodynamics of Human Movement

Ted Morris, John Trimble & Nick Touras
Rehabilitation Research and Development Center
VA Hines Hospital
Hines, IL 60141

Abstract

A PC compatible interactive computer graphics program has been developed to aid the researcher or clinician in exploring new ways to visualize the biodynamics of human movement. The design goal of the software package is to impose no constraints on the relationships that can be examined. A brief description of the software package's features will be discussed and illustrated. Our future plans include developing an inference engine that can be used to detect and study movement disorders by studying the spaces that knowledgeable clinicians use to analyze human movement.

Background and Statement of the Problem

Although human movement has been analyzed since the 1800's (Muybridge), we still know relatively little about the basic laws that govern the complex sequence of biomechanical and neural events that accompany a particular movement. During the past decade, several investigators have used computer graphics to help gain an understanding of these laws. Computer graphics-based models have been developed for walking, jumping and other activities (Lanshammer &Lindroth, 1987; Delp et al., 1990; Rowell & Mann 1989; Morris et. al, 1986; Lee et. al, 1990). However, most of these models are limited: they provide a means of visualizing only specific movements, sets of variables or only static displays. Accordingly, there is a need for a tool that provides clinicians and researchers with a method for understanding these laws.

Ideally, scientific visualization should offer investigators a means for drawing inferences regarding the causality of events that accompany particular events movement. Such an understanding should allow investigators to answer questions such as: (1) Is there a description of events in terms of topologies (within an appropriate space) that characterizes particular motion sequences? (2) Can this description be used to describe the control laws that govern these motion sequences; and (3) If this description exists, is it invariant and how does it change with movement disorders ?

In order to answer these questions, we have developed a software tool that allows virtually unlimited exploration of the relationships between the kinematic, dynamic and physiological aspects of human movement. Our tool allows these relationships to be explored easily by people with a minimum knowledge of computer programming.

Approach

Our package was implemented on a PC-based platform using an ATVista™ graphics coprocescsor (TrueVision, Inc.). We selected a menu-driven, multiple-window, real-time environment as the basis for our visualization package with the intent of imposing no constraints on the relationships that can be examined.

The software provides a means of defining 3-D and 2-D interactive windows. Three-dimensional windows may contain any dynamic or time-variying data which may be observed from any perspective. These data may include moving vector fields, body segments (rigid bodies or stick figures) or anatomical landmarks. The vector fields may comprise muscles that are created by connecting line segments between muscle origins and insertions or vectors that represent joint reaction forces, torques or instantaneous helical axes. Figure 1 shows an example of a 3-D motion window that consists of the measured ground reaction force vector superimposed on a vector that represents the computed trajectory of the whole-body center of gravity. This display was used to determine if relationships between these variables could be used to derive a low-dimensional, invariant description of the biodynamics of lifting (see Morris & Trimble, 1991).

Two-dimensional windows may be used to examine time-varying relationships as shown in Figure 2. These windows incorporate moving cursors that provide users with a means of visualizing relationships between two- and three-dimensional data. Users may move these cursors forwards or backwards through data with a variable rate. Two-dimensional windows may also be rescaled or rearranged to highlight or remove specific features of the data.

The software also provides a means for visualizing the differences between two or more sets of data. For example, users may create displays to visualize differences between body segment motions predicted using a hypothetical model and actual motions or differences in body segment trajectories that result from different strategies for performing certain tasks.

The user may also spawn other applications that may be used to process data contained in any window. These data may be evaluated graphically and readjusted by spawning other applications. Thus the software may be used as an integral part of a decision-making process for applications such as computer-aided design.

The software is currently configured to handle motion data either off-ine or in real-time from the WATSMART motion analysis system (Northern Digital, Inc.) although it may be re-configured to other motion analysis systems.

Discussion And Implications

A high-dimensional space is usually required to fully describe the complexities of human movement . Accordingly, it is difficult to fully appreciate and understand relationships such as those between motion dynamics and physiological or biomechanical variables without graphic visualization.

Much of the work on human movement has focused on creating realistic graphical depictions of articulated body segments. Our work differs from this in that it focuses more on providing users with a means of studying human movement through multiple two- and three-dimensional state spaces that may be customized to their needs.

We believe that the tool that we have created will provide investigators with a means of answering questions like those posed previously. Our future plans include developing an inference engine that can be used to detect and study movement disorders by studying the spaces that knowledgeable clinicians use to analyze and understand movement disorders, adding elementary variable transformations and adding the capability of visualizing 3-D time-variant or time-invariant relationships.

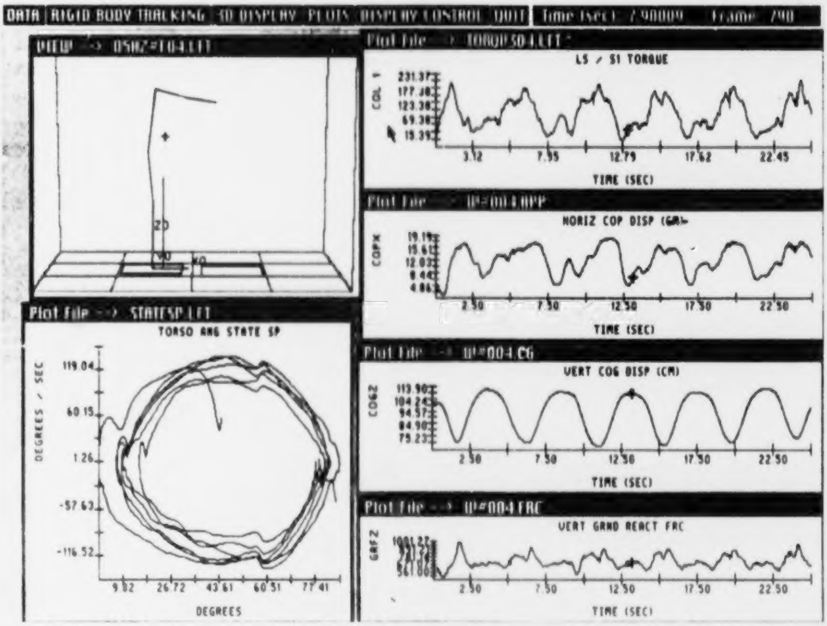

DATA
RIGID BODY TRACKING
3D DISPLAY
PLOTS
DISPLAY CONTROL
QUIT
Time (sec): 7.90009
Frame: 790
VIEW -> 05HZ=T04.LFT
ZO
XO
Plot File -> TORQ#SD4.LFT
LS / S1 TORQUE
COL 1
231.37
177.38
123.38
69.38
15.39
3.12
7.95
12.79
17.62
22.45
TIME (SEC)
Plot File -> IP=004.APP
HORIZ COP DISP (CM)
COPX
19.19
15.61
12.03
8.44
4.86
2.50
7.50
12.50
17.50
22.50
TIME (SEC)
Plot File -> STATESP.LFT
TORSO ANG STATE SP
DEGREES / SEC
119.04
60.15
1.26
-57.63
-116.52
9.82
26.72
43.61
60.51
77.41
DEGREES
Plot File -> IP#004.CG
VERT COG DISP (CM)
COGZ
113.90
104.24
94.57
84.90
75.23
2.50
7.50
12.50
17.50
22.50
TIME (SEC)
Plot File -> IP#004.FRC
VERT GRND REACT FRC
GRFZ
2.50
7.50
12.50
17.50
22.50
TIME (SEC)

Fig 2: Visualization of same subject performing the lifting task. Again the center of gravity and ground reaction force vector are represented in the view window. A cursors follows each of the curves as the motion proceeds. The plot windows (from top to left bottom) represent the computed lumbosacral torque vs. time, anterior-posterior center of pressure displacement vs. time, vertical center of gravity displacement vs. time, vertical component of the ground reaction force vs. time, and absolute trunk angle vs. absolute trunk angular velocity.

Acknowledgements

This research is supported by the Hines Rehabilitation R&D Center.

References

Delp S.L., Loan P.J., Hoy M.G., Zajac F.E., Topp E.L., Rosen J.M., "An Interactive Graphics-Based Model of the Lower Extremity to Study Orthopaedic Surgical Procedures", IEEE Transactions On Biomedical Engineering, Vol. 37, No. 8, August 1990.

Lanshammer H., Lindroth T., "Assessment of Tibial Osteotomy Using Gait Analysis. Part 1, Methods and Genuine Three-Dimensional Results Presentation", Biomechanics X-A, Human Kinetics Publ. Inc., 1987.

Lee P., Wei S., Zhao J., Badler N.I., "Strength Guided Motion", Computer Graphics, Vol. 24, No. 4, pp 253-262, 1990.

Morris T., Larson G., Donath M., "Real-Time Animation Of Human Walking For The Evaluation Of Pathological Gait", RESNA, June 23-26, Mpls, MN, 1986.

Morris T., Trimble J.,"Identification Of A Low Dimensional Invariant Function Of Lifting", RESNA, June 1991, Kansas City, Mo., 1991.

Rowell D., Mann R.W., "Human Movement Analysis", Soma, Vol. 3, No. 2, pp 13-20, 1989.

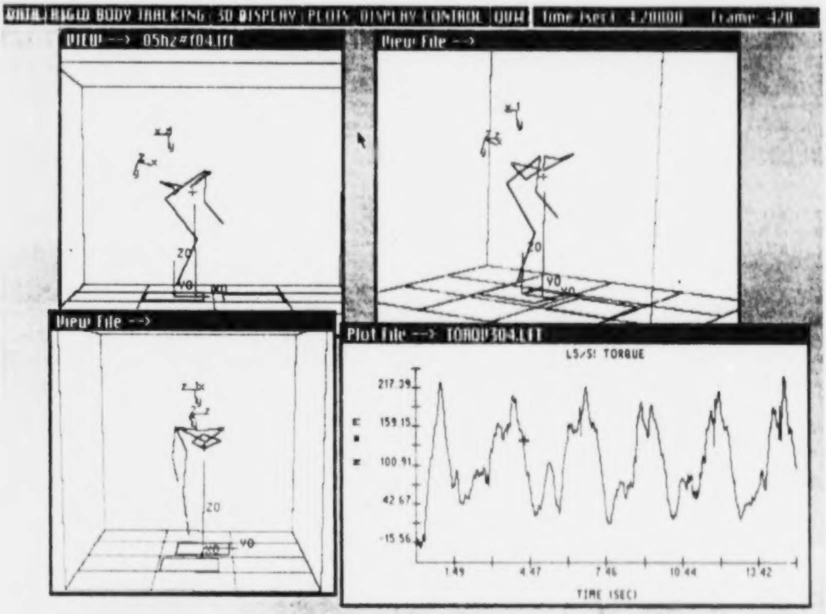

DATA
RIGID BODY TRACKING
3D DISPLAY
PLOTS
DISPLAY CONTROL
QUIT
Time (sec): 4.20000
Frame: 420
VIEW --> 05hz#f04.lft
View File -->
View File -->
Plot File --> TORQU304.LFT
ZO
VO
LS/S1 TORQUE
217.39
159.15
100.91
42.67
-15.56
1.49
4.47
7.46
10.44
13.42
TIME (SEC)

Fig 1: Visualization of a subject performing a lifting task viewed from three perspectives. The whole body center of gravity (the small cross hair) and ground reaction force vector are superimposed in each view. Note that the coordinate systems track the 3D position and orientation of the pelvis and upper torso. The digitized points represent digitized body land marks on the torso and pelvis. The stick figure model is superimposed over the rigid body model allowing one to easily visualize out of plane rotations which cannot be accounted for using the stick figure pin joint/linkage approach. The cursor is following the computed lumbosacral torque computed from an inverse dynamic model based on the motion of the stick figure.

Vertical Vestibular Stimulation and Cerebral Palsy
A Preliminary Report

James W. Fee, Jr. and James W. Labuzzetta
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

ABSTRACT

The object of this paper is to present a preliminary report on an attempt to quantitatively analyze the effect of vertical accelerations on athetoid movement seen in cerebral palsy. In order to accomplish this, workers at the Alfred I. duPont Institute have constructed an electro-mechanical system which can apply a predetermined vertical acceleration to a child and his/her normal seating system. The researchers also have at their disposal equipment which can accurately and precisely measure arm flexion and extension as it tracks a moving target. Using these two devices, a study has commenced with the intent of evaluating voluntary movement of the forearm about the elbow joint in terms of its power spectral density. Comparisons have been performed of attributes of these densities before and after the subjects were stimulated in a controlled environment using known statistical methods.

BACKGROUND

Cerebral palsy is a nonspecific term used to describe a persistent qualitative motor disorder caused by nonprogressive damage to the central nervous system. A predominant clinical manifestation of the disorder is athetosis, which is characterized by slow, writhing, involuntary movements which lack fixed amplitude, rhythmicity or direction.

Vestibular stimulation has been recognized by rehabilitation clinicians as a valuable part of treatment programs for those with this and similar motor dysfunctions. The benefits of this type of treatment have been identified in the literature as: improved alignment, improved balance reactions, and more normalized tone.

Most often vestibular stimulation takes the forms of circular or rotary motion about a vertical axis. This treatment is usually performed by placing the child in a swing and causing it to spin in a circular fashion. Alternatively, the child is made to lie prone on a scooter board while being pushed in a circular motion.

Another form of vestibular stimulation has been recently introduced in the guise of Therapeutic Horseback Riding. The literature reports various positive effects resulting from sessions on horseback. The increasing use of this modality of therapy places a burden on those recommending and providing it to show a physiological and economic justification for its use. It is the purpose of our ongoing investigation to attempt to quantify the effect of vertical vestibular stimulation on athetoid movement as well as on cerebral palsy in general.

The authors have designed and built a vertical acceleration table. This table is capable of vibrating a subject in the vertical plane at various speeds and amplitudes which are physiologically consistent with those experienced by a rider on a horse. In addition, the authors have in place the means for precise measurements of elbow joint flexion and extension. This measuring device, know as the Elbow Tracker (ET) is described elsewhere in these Proceedings[1]. The data collected by the ET has been analyzed by various statistical methods in an attempt to show a correlation between vertical accelerations and changes in the subject's motor performance.

RESEARCH QUESTION

Does vertical oscillation of the entire body have any effect on the cerebral palsied subject's ability to track a computer generated target?

METHODS

Vertical Acceleration Platform- A vertical acceleration platform has been designed and built by the authors at the Applied Science and Engineering Laboratories of the Alfred I. duPont Institute. The completed system has been in operation since July of 1990. The platform, Figure 1, is capable of vibrating a subject in the vertical plane with adjustable maximum vertical acceleration. The platform has been designed to apply accelerations within the range of those employed in current modes of therapy (e.g. the value of acceleration in horseback riding). That is, acceleration will not exceed 1.79g, the maximum vertical acceleration of a trotting horse[2]. In the present study the acceleration was limited to a value that subjects felt comfortable with, usually about 0.7g.

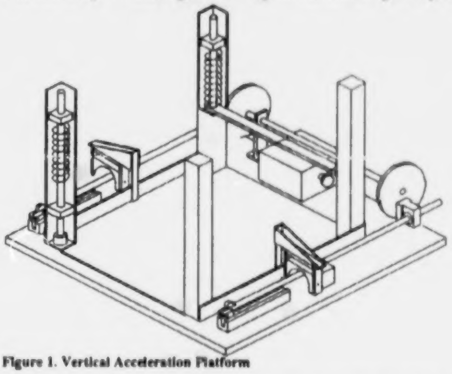


Figure 1. Vertical Acceleration Platform

Target Tracking- The Elbow Tracking system used in this experiment is extensively outlined elsewhere in these Proceedings[1] and will not be repeated here.

Data Collection- Arm position data for 8 cerebral palsied subjects (mean age = 14.4 yrs) was collected at four intervals: before stimulation, immediately after stimulation, and at 15 and 30 minutes after stimulation. The subjects were presented with 7 separate tracking tasks:

1. Tracking a 0.5 hertz sinusoidal target
2. Tracking a 1.0 hertz sinusoidal target
3. Tracking a "random" target
4. Flexing and extending the elbow as fast as possible or "freewheeling"
5. Hold the forearm as still as possible
6. Tracking a sinusoidal target at a frequency chosen by the tester
7. Tracking a sinusoidal target at a second frequency chosen by the tester

In each case the tracking task lasted 16 seconds and was administered by a certified physical therapist.

Data Analysis- Elbow angle data was analyzed by applying a Fast Fourier Transformation. The result of this transformation was a power spectral density (PSD) curve showing frequency and amplitude distributions in the range from 0 to 30 hertz. We found early in the testing that most of the significant information was contained in a bandwidth between 0 and 5 hertz. One example of such a PSD curve is shown in Figure 2.

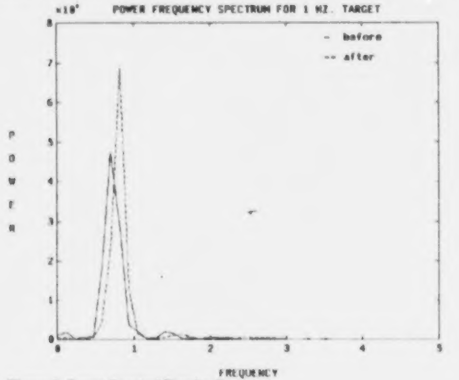


Figure 2. Power Spectral Density Curve

In his work with athetoid movement, Neilson[3] suggested that the frequency range between 0.3 and 0.6 hertz might be of significance, therefore some of our analysis centered on this range. In the analysis of our data five separate attributes were applied to the power spectral density curves obtained from the fast fourier transformations. These five attributes were:

Total Power- Obtained by integrated the frequency spectrum over the entire range (0 - 30 Hz).

Frequency at Maximum Power- The frequency at which the power spectral density curve reaches its maximum value.

Maximum Power- The value of power at the highest point on the spectral density curve.

Moment of Distribution about Maximum Power- Obtained by summing the power spectral values over the entire range with each value multiplied by the difference between its frequency and the frequency at Maximum Power.

Partial Power- The percentage of total power under the curve between 0.3 and 0.6 Hz.

In another paper presented in these Proceedings[1], the authors have shown that differences exist in the above five attributes when they are applied to data gathered from normal vs. cerebral palsied subjects. In applying the tests to the present study, we sought to find a change in the data which moved the attributes toward the more normal values. For example, in Figure 2, the spectral density curve for data taken immediately after stimulation reflects an increase in power under a maximum frequency which is shifted toward the target frequency. The curves in Figure 2 also demonstrate a reduction in the power under the curve in the 0.3 to 0.6 Hz. range.

In addition to the spectral analysis several other tests were applied to the data. One such test examined the maximum time a subject held his/her arm in a given position while attempting the "hold still' tracking task.

RESULTS

Extensive statistical analysis of the data from our seven tracking tasks using our five measurements has revealed that while there appears to be trends in the data toward more normalization of values after vestibular stimulation, no single task or measure has resulted in a statistically significant improvement. By far the most interesting results have come from our examination of "holding still" tests. In this case six out of our eight subjects showed a tendency toward a greater ability to remain in one position longer after vestibular stimulation than before. Figure 3, shown below, reflects this trend. Unfortunately, as in all of our other tests, the differences found in the data before and after stimulation were not statistically significant.

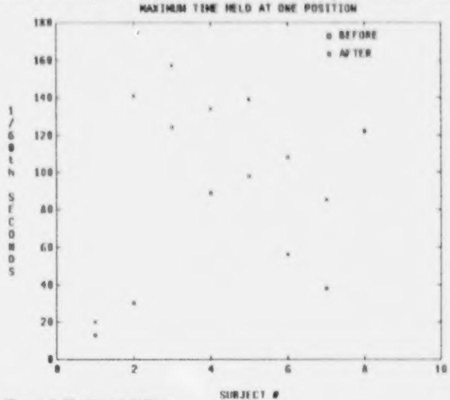


Figure 3. Holding Still Test

DISCUSSION

Based on the comments of the therapist performing the tests, as well as others in the room with the subjects at the time of the tests, the authors feel the lack of statistical significance seen in the differences in the data collected before and after stimulation is not a statement about vertical vestibular stimulation. Rather these results tell us that our test were inappropriate, our population too small, and the extent of athetosis vs. spasticity in the individual subjects was not clearly defined. We feel the trends in the data are encouraging and reflect what was expected. Our work is ongoing and in the future other tests will be applied which reflect more of the physiology involved.

ACKNOWLEDGEMENTS

Funding for this research was provided by the Nemours Foundation.

The Authors wish to thank Arthur A. Baechel, Jr. and Robert J. Bell for their work in the construction of the Vertical Acceleration Platform. We also wish to acknowledge Katherine Samworth for her work in collecting the data.

REFERENCES

1. Fee, James W. Jr. and Labuzzetta, James W., "The Polhemus Isotrack as an Assessment Tool for Cerebral Palsy", Submitted to: Proceedings of the 1991 RESNA Conference.
2. Riede, D. "Physiotherapy on the Horse" Therapeutic Riding Services, Maryland, 1988, p. 75.
3. Neilson, Peter, D., "Measurement of Involuntary Arm Movement in Athetotic Patients", J of Neurol., Neurosurg, and Psy. 1974, Vol 37, 171-177.

James W. Fee, Jr. and James W. Labuzzetta
Applied Science and Engineering Laboratories
Alfred I. duPont Instituite
P. O. Box 269
Wilmington, DE 19899
Phone: (302) 651-6830

A constraint for human arm motion in joint space

9.4

Tariq Rahman
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

ABSTRACT

This paper describes the development of a constraint in arm joint-space, for routine motions. It was postulated that the angle of the upper arm-forearm plane about the shoulder-wrist line (γ), for routine tasks remains constant or varies minimally. A kinematic model for the arm was developed. γ was constrained to remain constant and the motion for the arm was analyzed for a specific hand trajectory. The motion was compared to experimental motion and a pseudo-inverse optimization methods. The results were in good agreement with actual data, suggesting the validity of this geometric constraint.

BACKGROUND

Human arm motion has been examined previously [1,2,3]. Typical questions that need to be addressed are, what are the criteria for motion, is the arm controlled in joint space or Cartesian space.

Information on the movement of the arm and its associated biomechanics, as well as being useful to the medical field would provide much needed data for engineers, in particular prosthetists and roboticists. The control used by the CNS for motion would help design artificial devices for the disabled.

Three degrees of freedom are required for positioning the hand in space. The human arm possesses four major d.o.f. for this purpose. The human uses all four d.o.f. by either minimization of a merit function such as energy, effort, optimal muscle lengths; or by finding a relationship between variables

This work does not propose a relationship between specific joint variables, as considered previously [2]. That approach may or may not answer the broader question of control. Instead,the joint constraint proposed is the rotation of upper arm-forearm plane. This constraint is simple, although the relationship between the joints is complex.

RESEARCH QUESTIONS

What are some of the criteria the CNS applies to control the arm? and can these complex constraint relationships be represented as simpler constraints in joint or Cartesian space?

METHOD

The arm was modelled as a 4 d.o.f., two link system with Euler angles at the shoulder (ϕ, θ, ψ), and the elbow angle (α), figure 1. The inverse kinematics that yield the four joint angles, given xyz coordinates of the hand, were solved. The geometric constraint, i.e., fixed-γ, was adjoined to the inverse kinematics procedure by way of describing the four joint angles when the links are both in the vertical plane, then rotating the plane about the shoulder-hand axis by an angle γ. This was accomplished by utilizing Rodrigues formula for rotation about an arbitrary axis.

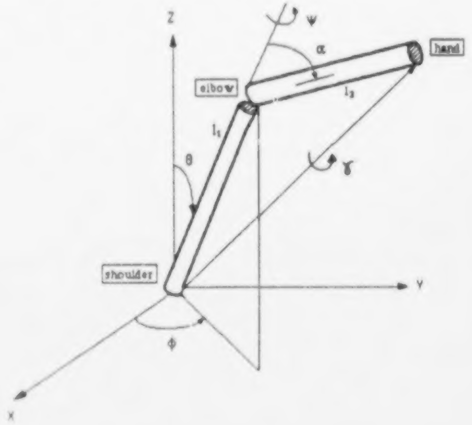


Figure 1 Kinematic configuration of the arm

Upon examination of experimental data, it was seen that there was a small variation in angle γ for the motions examined. In an attempt to predict this variation, a variable γ was fed into the Rodrigues formula. γ was varied in proportion to the change in the angle between the upper arm-forearm plane and a line tangent the hand trajectory.

In addition, an optimization criterion that minimizes the total travel of the joints, using the pseudoinverse technique, was obtained. This criterion was selected because it minimizes small changes in displacement, which relates to mechanical energy.

Experimental data was collected for human subjects for four routine tasks; arm curl, drinking, swinging, pulling. The system used was the WATSMART system that employs LED's placed on the subject and gives xyz information of the emitters. The data were collected at 40 Hz and filtered at 4 Hz using a Butterworth low-pass filter. The xyz data were then mapped into joint-space and differentiated twice, using finite difference to yield velocities and accelerations, thus enabling comparison of joint variables between the experimental and the three theoretical models.

RESULTS

The results for joint angle displacements for two of the angles for the "pulling" motion are shown in figure 2. The pulling motion is similar to opening and closing a door; the right hand starts at a position in front of the left shoulder, then is brought down to the right hip, and back again. The figures illustrate the four methods described earlier (all have the same hand trajectory). The graph shows that the γ-constraint methods are close to the experiment but the pseudoinverse deviates from actual data. The results from the other motions displayed similar results.

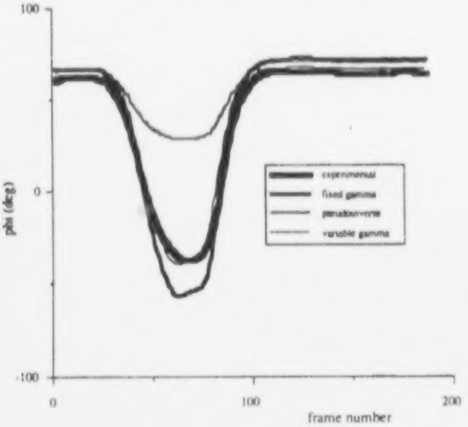


Figure 2a Angular displacement for'pulling' motion, angle ϕ

DISCUSSION

The motions resulting from using the pseudo-inverse technique tended to pull the elbow in towards the body. This could be the minimum energy solution, however it is not only anaesthetic, but goes beyond human joint limits. The fixed-γ and variable-γ constraints are close to actual motion suggesting the validity of this constraint. This is not to say that this is the criterion used by the CNS, but this constraint in joint space may be a representation of more complex constraints. Motion that results from applying this relatively simple geometric constraint is shown to be aesthetically close to human motion, which is important when considering application to a prosthetic arm.

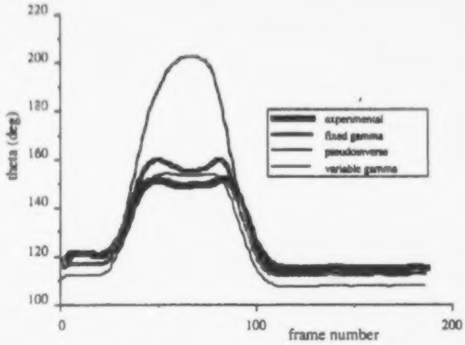


Figure 2b Angular displacement for 'pulling' motion, angle θ

REFERENCES

1. Flash, T. and Hogan, N., *"The Coordination of Arm Movements: An Experimentally Confirmed Mathematical Model"*, J. of Neurosci., Vol. 5, No. 7, pp. 1688-1703, 1985

2. Lacquaniti, F., Soechting, J.F. and Terzuolo, S.A., *"Path Constraints on Point-to-Point Arm Movements in Three-Dimensional Space"*, Neuroscience, Vol. 17, pp. 313-324, 1986

3. Bizzi, E. et. al., *"Posture Control and Trajectory Formation During Arm Movement"*, J. of Neurosci., Vol. 4, pp 2738-2744, 1984

Tariq Rahman
Applied Science and Engineering Laboratories
A.I. Dupont Institute
P.O. Box 269
Wilmington, DE 19899

Identification Of A Low Dimensional Invariant Function Of Lifting

Ted Morris & John Trimble
Rehabilitation Research and Development Center
VA Hines Hospital
Hines, IL 60141

Introduction

Problem Statement:

Most of the studies on lifting have examined its physiological and biomechanical sequelae using static, quasi-static, or dynamic musculoskeletal models (Chaffin 1987, Freivalds et al., 1984, Schipplein et al., 1990, Norman & McGill, 1986). For example, Schipplen et al. (1990) applied Andriacchi's (1980) inverse dynamic model to determine the relationship between the amount of weight lifted and the sagittal-plane torques at the lumbosacral junction and the hip and knee joints. They found that certain dynamic joint characteristics were invariant with the amount of weight that was lifted.

We believe that these findings suggest that there may be a more global invariant relationship that can be used to describe the dynamics of lifting. In fact, McIntyre (1990) states that for many submaximal lifting tasks, the "human may be regarded as a 'self-optimizing' machine in which the biological system becomes coordinated to possibly accomplish a task with minimum energy expenditure, to maintain balance and to minimize pain." Our goal was to identify kinematic or kinetic variables that might define such a relationship.

A clue to this relationship may lie in the fact that balance is required for proper lifting. When the body is balanced, there is a unique relationship between the center of gravity (COG), center of pressure (COP) and ground reaction force vector. The relationship between these variables might be used to develop an invariant description of lifting dynamics since they also reflect the overall dynamic behavior of the biomechanical system. The purpose of our study was to test this hypothesis.

Potential Impact of Research Study:

A simple, yet robust relationship that describes the dynamics of lifting could be used to analyze and teach lifting strategies or to identify people with low back injuries. Additionally, the COG, COP and ground reaction force vector may be obtained using a force platform thus providing an inexpensive and simple method for studying low back injuries.

Significance of Research:

An invariant relationship between COG, COP and the torque at various joints during lifting might reveal specific characteristics of the neural and musculoskeletal systems that control lifting. Such a relationship might also reveal the influence of balance on postural control during lifting.

Method:

Three volunteer subjects were used for our preliminary study. None of them had a history of low back pain. They were asked to lift a 10 kg load with handles placed 0.28 m apart from an initial position that was 0.28 m from ground and 0.54 m in front of their ankles to a final position that was shoulder height with their arms fully extended. Each subject lifted the load three different ways: (1) preferred or free style, (2) bending predominantly at the knees and (3) bending predominantly at the hip. All subjects were told to perform the lift at their preferred rate for a minimum of 10 seconds. Subjects were allowed to practice lifting before any data were collected and they were allowed to rest at least 1 minute between lifts.

The ground reaction force and moment vector components were recorded using a six-degree-of-freedom force platform (AMTI, Inc.) upon which the subjects stood during the course of the lift. A similar force platform was used to record the applied reaction force acting on the hands during the lift. Signals from the force platforms were digitized using a 16-channel analog-to-digital converter (WATSCOPE, Northern Digital, Inc.) and filtered digitally with a second-order lowpass Butterworth filter with a cutoff frequency of 10 Hz.

The three-dimensional position of infrared light-emitting-diode arrays (IREDs) placed on one side of the subject's body at the wrist, elbow, shoulder, bony prominence of the femoral trochanter, knee and ankle were recorded simultaneously using a two-camera motion tracking system (WATSMART, Northern Digital, Inc.). All kinematic data were sampled at 60 Hz and filtered digitally using a second-order lowpass Butterworth filter with a cutoff frequency of 5 Hz. We also digitized the locations of the posterior aspects of the calcaneous and distal ends of each subject's great toe to define his base of support.

The location of the subjects' L5/S1 articulations were computed on the basis of the geometric model in which body segments were modeled as an articulated seven-link model (Freivalds et al., 1984). The inertial properties of the body segments were estimated using anthropometric data obtained from Plagenhoff (1983).

The subjects' resting COPs prior to the lift were estimated from kinematic and force platform data obtained while they were in a quiescent, erect posture. These data were used to determine the deviation of their COPs during the lift.

The force data were processed to obtain the trajectory of the body COG in the sagittal plane and the point of application of the ground reaction force in the horizontal plane (Shimba, 1984). We used an inverse dynamic model (Freivalds, 1984, Schipplein, 1990) to predict the reaction torques at the hip, knee and ankle joints using the three-dimensional target data and the reaction forces at either the free or fixed ends of the body (e.g., hands or feet). We also computed the axial compression force acting through lumbosacral disc using the method developed and tested by Freivalds (1984) and Chaffin (1987).

Results:

Interactive motion analysis software (Morris et al., 1991) was used to conduct an exploratory analysis of the relationships between the trajectories of COG, COP, and ground reaction force vector and joint dynamics. Visualization of these relationships suggested that a combination of the vertical trajectories of the COG and the ground reaction force vectors and the horizontal trajectory of the COP might be strongly correlated with the torque at the lumbosacral junction.

Accordingly, we applied multiple linear regression to these variables and found that there were linear combinations that accurately predicted the torque at the lumbosacral junction, the hip joint and to a lesser extent the knee joint. Likewise, there was a linear combination that accurately predicted the compression force acting through the lumbosacral disc (L5/S1) (Fig. 2). The first linear regression used the vertical displacement of the COG and the vertical component of the ground reaction force vector. The second linear regression added the anterior-posterior displacement of the COP as a third independent variable. Figure 1 shows the excellent agreement between the predicted and actual joint torques and disc compression force. The analysis of variance for the L5/S1 torque are summarized in Table 1. The shapes and magnitudes of the predicted torques calculated using either the fixed or free end models were in general agreement with values published in the literature (Schipplein et al., 1990). The results of the 3-variable regression analysis clearly show that the greatest variance in the torque at the lumbosacral junction is due to the anterior-posterior component of the COP trajectory. The results of the 2-variable regression anaylsis show that the greatest variance in the torque at the lumbosacral junction is due to the vertical displacement of the COG. Note that the correlation coefficients, (R in Table 1), reveal the improvement in the curve fit by adding the COP trajectory. The results of the other joints also followed this trend.

TABLE 1: REGRESSION ON TORQUE ABOUT L5/S1 JUNCTION

SUBJECT	CORR, R	PARTIAL F[1]			STYLE[2]
		COG$_Z$	GRF$_Z$	COP$_X$	
ALV307	0.949	0.0060	70.623	2147.3	FS
ALV305	0.959	220.80	77.800	1951.9	BK
ALV302	0.976	27.200	187.90	2357.0	BH
TMV304	0.974	454.60	928.90	3226.7	FS
NTV302	0.976	6675.6	143.40	11674.	FS
NTV305	0.934	682.30	25.700	7091.2	BH
ALV307	0.847	458.4	1067.3	*	FS
ALV305	0.860	1606.5	253.40	*	BK
ALV302	0.900	2284.2	221.10	*	BH
TMV304	0.916	1313.9	742.10	*	FS
NTV302	0.787	2364.9	224.80	*	FS
NTV305	0.703	1558.2	723.50	*	BH

[1] The partial F statistic is an indicator of the amount of variance explained in the torque curve due to the corresponding independent variable in the presence of the other independent variables.

[2] FS = Free Style, BK = Bending Knees, BH = Bending at Hip.

* indicates regression on COG$_Z$ and GRF$_Z$ only where

COG$_Z$ is the vertical component of whole body center of gravity trajectory.

GRF$_Z$ is the v ertical component of ground reaction force vector.

COP$_X$ is the anterior-posterior component of the center of pressure minus the average COP computed for the subject in standing errect posture.

Discussion:

The torques that we are able to predict using a simple, low-dimensional model are in excellent agreement with published and actual data. This supports our hypothesis that there is a global invariant that may be used to describe the dynamics of lifting. The variations in the joint torques that are predicted from the inverse dynamic model are due to uncertainties in the anthropometric and kinematic data. This is not unusual since investigators have shown previously that uncertainties in kinematics have a profound effect on torques obtained from dynamic models (Patriarco et al., 1981).

In order to completely identify invariances between human body joint dynamics and the descriptors of whole body behavior, it is paramount to reduce uncertainties in the predicted joint torques. We will accomplish this in the future by using more accurate six-degree-of-freedom rigid body model.

Acknowledgements

This research is supported by the Hines Rehabilitation R&D Center.

References:

Andriacchi, T.P., Andersson, G.B.J., "A Study Of Lower Limb Mechanics During Stair Climbing" J. Bone Jt Surg. 62A, pp 749-757.

Chaffin, D.B., "Computerized Models for Occupational Biomechanics" Biomechanics X-A, Human Kinetics Publ. Inc., 1987.

Freivalds A., Chaffin, D.B., Garg, A., Lee, K.S. "A Dynamic Biomechanical Evaluation Of Lifting Maximum Acceptable Loads", J. of Biomechanics Vol. 17, No. 4, pp 251-262, 1984.

Morris T., Trimble J., Touras N., "An Interactive Tool for Visualizing the Biodynamics of Human Movement" RESNA, 1990.

Norman R.W., McGill, S.M. "Dynamically And Statically Determined Low Back Moments During Lifting" J. of Biomechanics Vol. 18, No. 12, pp. 877-885, 1985.

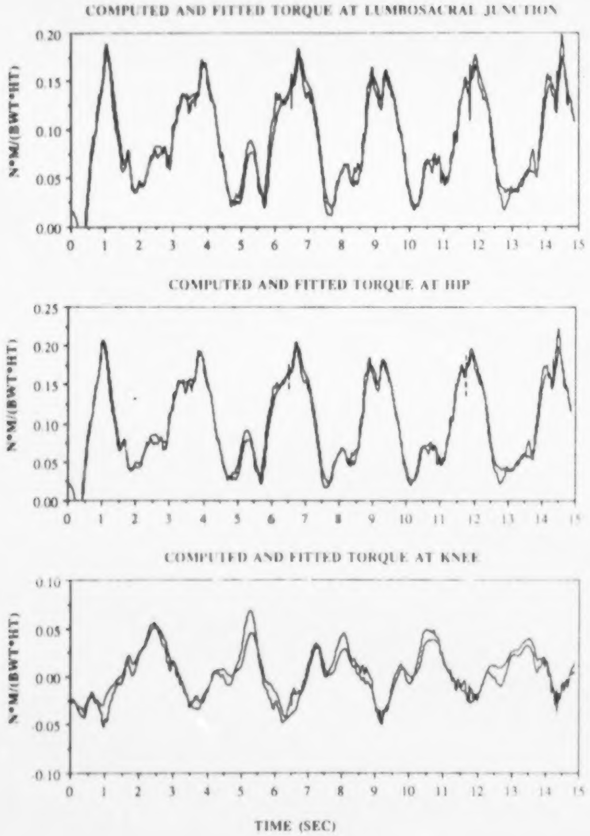
Norman R.W., McGill, S.M."Partitioning of the L4-L5 Dynamic Moment into Disc Ligamentous and Muscular Components During Lifting" Spine Vol. 11 No. 7 pp 666-678, 1986.

Patriarco A.G., Mainn R.W., Simon S.R., Mansour J.M., "An Evaluation Of The Approaches Of Optimization Models In The Prediction Of Muscle Forces During Human Gait" J. Biomechanics Vol. 14, No. 8, pp 513-525.

Plagenhoff S., Evans F, G., Abdelnour T., "Anatomical Data for Analyzing Human Motion" Research Quarterly For Exercise And Sport Vol. 54, No. 2, pp 169 - 178, 1983.

Schipplein O.D., Trafimow, J.H., Andersson, G.B.,Andriacchi, T.P. "Relationship Between Moments At The L5/S1 Level, Hip And Knee Joint When Lifting" J. of Biomechanics Vol. 23, No. 9, pp. 907-912, 1990.

Shimba, T. "An Estimation Of Center Of Gravity From Force Platform Data" J. of Biomechanics Vol. 17, No. 1, pp 53-60, 1984.


COMPUTED AND FITTED TORQUE AT LUMBOSACRAL JUNCTION

COMPUTED AND FITTED TORQUE AT HIP

COMPUTED AND FITTED TORQUE AT KNEE

Fig 1a-c.: Curves of computed torques based on inverse dynamic model and fitted 3-variable regression equation which used COG$_Z$, COP$_X$, and vertical component of grnd reaction force, GRF$_Z$. All torques are normalized with respect the subject body weight * height in Newtons and meters respectively. The first peek represents the subject lifting the load for the first time.

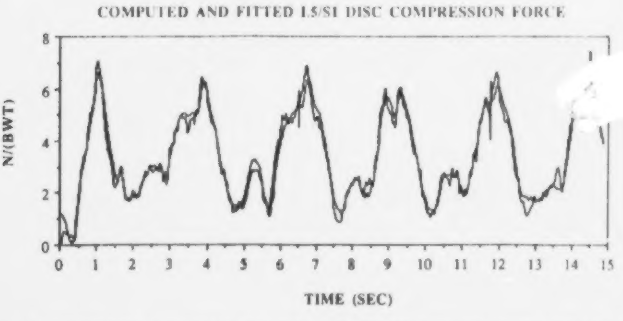

COMPUTED AND FITTED L5/S1 DISC COMPRESSION FORCE

Fig 2: Curves of computed disc compression force and fitted 3-variable regression equation using the independent variables as described in text and Fig 1. Disc compression force is normalized with respect to the subject's body weight.

9.6 DESIGN OF THE PATIENT INTERFACE FOR A COMPUTER-BASED TREMOR CHARACTERIZATION SYSTEM

Diane M. Brongo and Michael J. Rosen
Newman Laboratory for Biomechanics and Human Rehabilitation
Mechanical Engineering Department
Massachusetts Institute of Technology

ABSTRACT

Pathological tremor is characterized by rhythmic, oscillatory motion that occurs at rest or during activity. In severe cases the tremor may have sufficient amplitude to obscure any underlying voluntary activity, making normal function difficult or impossible. While drug therapies exist that can reduce tremor in some cases, prediction of drug effectiveness from current diagnostic categories is extremely unreliable.

The CSCAT (Computer-based System for Clinical Assessment of Tremor) has been designed to test the hypothesis that the differential diagnosis of tremor may be accomplished by the imposition of controlled mechanical loads on tremorous limbs while the patient performs a well-defined task. The "load response" of tremor, i.e. how the objective tremor parameters change in the presence of varying mechanical loads, is expected to reveal differences among tremors which would not appear under conventional assessment, resulting in a more objective and definitive tremor classification system. It is hypothesized that tremor categories in this way will successfully predict drug effectiveness once the necessary experimental correlation has been established.

INTRODUCTION

Tremor, one of the most common movement disorders, is characterized by rhythmic, oscillatory motion that occurs at rest or during activity. [1] [2] "Physiological tremor" is present in normal persons at frequencies of 8 - 12 Hz. [3] In pathological cases the tremor may be severe enough to obscure any underlying voluntary activity, making normal function difficult or impossible. [4]

The goal of this work is the development and evaluation of an improved approach to differential diagnosis of tremor based on the response of the patient to controlled mechanical loads. This project is motivated by the unpredictability of drug effectiveness which results from incomplete and insensitive characterization of pathological tremors by traditional assessment techniques which are largely subjective. [5] **Four neurologists surveyed indicated that between 25% and 70% of their patients did *not* respond as hoped to the drugs prescribed, clearly demonstrating the need for an improved drug prescription strategy.** These new methods employ sensitive, objective instrumentation for clinical data collection and computer-based signal processing tools for analysis, both of which have become fairly common in tremor research.

The load response of tremor, i.e. how its objective signature changes when tasks are performed in the presence of varying mechanical loads, is expected to reveal differences among tremors which would not appear under fixed conditions, resulting in a more definitive tremor classification system. The prototype clinical system which has been completed to test this idea is known as CSCAT. Aspects of its design will be presented below.

In the next part of the investigation the new tremor categories will be correlated with the patients' response to drug treatments. If the hypothesized correlation is found, the result will be a drug prescription strategy based on CSCAT that may then replace the standard trial-and-error treatment strategy.

CSCAT (Figure 1) is a mobile 1-degree-of-freedom manipulandum consisting of three parts: a motor that is digitally controlled via feedback from torque and kinematic transducers to simulate various levels of springs, masses and dampers [6]; a patient interface whereby mechanical loading is applied to the patient's limb and a target is displayed; and a computer based-assessment manager that handles the collection and analysis of all data and interfaces with the clinician. The assessment task requires the patient to execute a target-tracking task which excites his/her tremor.

Design of the Limb Interface

Degree of Freedom Selection

Tremor is seen in all parts of the body, from the head and neck to the distal portions of all extremities. It is not practical or necessary to assess clinically all tremor sites, but the manipulandum should be capable of measuring at least a few for two reasons. First, not all patients have tremor in the same place, and secondly it has not been shown which degrees of freedom (DOFs) will yield the best results for prediction of drug effectiveness. The particular choice of DOFs depends on both human and machine-related factors.

Persons with tremor in the lower body can compensate for some of the resulting disabilities with a wheelchair but tremor in the upper body can cause more serious functional and aesthetic disabilities. These people are more likely to seek drug treatment to help their tremor and so will be more in need of this diagnostic tool. Therefore assessment can be confined to the upper body. [7]

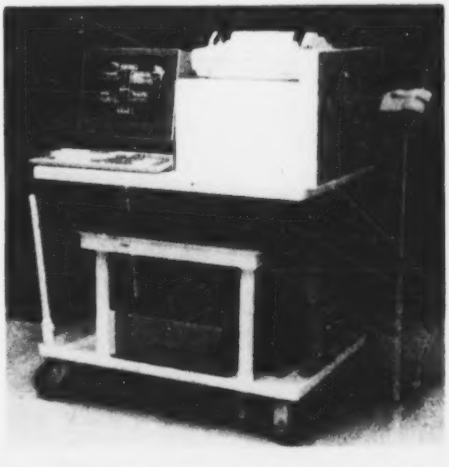


Figure 1. CSCAT (Computer-based System for the Clinical Assessment of Tremor).

The patient must perform a 1-degree-of-freedom tracking task. For the assessment to be reliable this DOF must be isolated from all other DOFs that could produce motions at the measurement site. These interfering motions must then be restrained, a design challenge that is more difficult for some DOFs than others.

The axis of motion under assessment must be aligned with the motor shaft, i.e. either the motor axis or subject's body will need to be reoriented to accommodate all DOFs under study and a range of subject sizes. The motor axis may be vertical, horizontal or possibly adjustable but must be easily aligned with all human motion axes chosen for study. In addition, the selected human movements should have comparable angular range of motion and not be so forceful that an unacceptably large or expensive motor is required to create the virtual environment.

The DOFs chosen for inclusion in the present implementation of CSCAT meet the design requirements acceptably. They include: elbow flexion/extension, forearm pronation/supination, and wrist flexion/extension, which can all be accommodated with a horizontal motor axis orientation thereby avoiding an adjustable motor mount. All assessments can be conducted for both the left and right arms.

Design Criteria for Arm-to-Motor Couplings

Coupling a single joint axis of rotation to a motor axis poses a considerable design challenge. The arm-to-motor couplings must satisfy the clinicians who conduct the assessment, the human safety committees, the sponsors funding development of the device, and of course the patient who is wearing them.

The system must couple the loading (motor) and instrumentation to the joint so the acquired signal accurately represents the actual joint angle. Attachment must be made to the outside of the body. This means that the coupling between limb motion and the attachment is characterized by the mass, compliance and damping of both the body tissues and the attachment itself. Since the objective of this device is to apply controlled loading to the body and to measure and analyze the angle, angular position and torque of the limb segment, values for the above parameters must be chosen to have little or no effect on the actual applied load.

In addition to these functional qualities of the coupling, a device that can fit all subjects and test both the right and the left arms is desirable. The coupling should also be easy to connect to both the patient and the motor for the convenience of the clinicians who will conduct the assessment.

For the patient's sake, the interface should be safe and look unimposing. In addition, since a session with the device is expected to last up to one hour the attachment must be comfortable for at least that length of time.

As this device is a prototype for a production diagnostic tool, its manufacturing cost should be kept to a minimum. Therefore the materials and components used in the couplings should be standard and inexpensive wherever possible, and custom parts should be kept to minimum. In addition, the planned experimental evaluation may take years so the prototype couplings as well as the rest of the device should be durable.

Arm-to-Motor Coupling Designs

All arm-to-motor couplings attach to the motor shaft by means of a keyed coupling rod and a knob-actuated split clamp which is firmly connected to the motor shaft. This clamping mechanism provides a strong, uniform clamping force on the rod while allowing the rod to be clamped anywhere along its length. Round tubing was chosen for the coupling rods as it has a greater stiffness-to-weight ratio than solid rods or square tubing of the same size. The motor end of each coupling rod is keyed so the couplings can only be attached to the motor in the correct rotational position. Most metal structural parts are aluminum, chosen for its high stiffness-to-weight ratio, easy availability and low cost. The pieces were anodized clear for a tougher and more aesthetically pleasing finish.

The Universal Wrist Coupling shown in Figures 2 and 3 is used for both pronation/supination and wrist flexion/extension assessments with the left or right arm. The configuration of the coupling is easily altered by loosening the knob, rotating the handle until it hits one of the limit stops, and tightening the knob. The handle is offset 12 degrees to account for the natural grip line of the hand; this allows the evaluations to be conducted with the patient's arm in a comfortable, natural position. The handle is covered with a firm foam handle-bar grip that is comfortable for the subject without adding excessive spring or damper effects to the system.

For the pronation/supination exercise the patient grips the handle at an appropriate place along its length so the forearm axis lines up with the motor axis. For wrist flexion/extension the coupling is adjustable. To accommodate variations in length from the center of the patient's grip line to the wrist axis the keyed coupling rod is slid to the appropriate position in the split clamp. A scale embossed on this rod allows each patient's setting to be recorded.

The elbow flexion/extension assessment requires quite a few more parts. The natural grip of the hand cannot be used for this assessment since forces would then have to be transmitted through the wrist joint. Instead the forearm is splinted (AliMed Rigid Wrist/Thumb Immobilizers, about $40 each) and coupled to the motor shaft via a sliding dovetail connector and a keyed coupling rod (Figure 4). In addition to providing a stiff coupling to the arm, the splint immobilizes the wrist, suppressing any wrist tremor and preventing any distractions and data contamination that a tremorous hand may cause.

The sliding dovetail connector joins the keyed coupling rod to the splint and provides for adjustment perpendicular to the forearm axis. The keyed coupling rod then slides into the split clamp and is adjusted along the forearm axis to align the elbow axis with the motor axis. Both connectors have embossed scales so the patients' settings can be stored for future trials.

Design Criteria for Arm Restraint

For the motor to apply a load across a joint, and for the movement parameters to be measured accurately, the distal limb segment must be firmly attached to the motor shaft while the proximal segment is secured to the motor's mechanical reference, in this case the cart. A system to restrain the distal limb segment must be devised that once again satisfies the clinician, the sponsor and the patient.

Design requirements are essentially the same as for the Arm-to-Motor Couplings. Stiffness, comfort, ease and range of adjustability, economy of manufacture, durability and unintimidating appearance are the major requirements.

Arm Restraint Design

The arm restraint system consists of the following four parts (named for their function and/or appearance): the support tower, the T-bar, the adjustable leg with foot, and the cushion post. It is shown set up for pronation/supination (Figure 5) and wrist flexion/extension (Figure 6). The setup for elbow flexion/extension is similar to that shown in Figure 6 except the armrest is angled the opposite way. The support tower is securely fastened to the cart. The T-bar fits into the top chamber of the support tower and is clamped with a knob-actuated set-screw. The adjustable leg then slides into one of the three openings on the T-bar and is clamped in place the same way. The cushion post is keyed so that it can only fit into the adjustable leg one way and will not rotate once it has been inserted. It too is fastened in place with a knob-actuated set-screw. Next the cushion atop the cushion post is rotated to the desired position and another knob tightened to hold it there. Finally, the arm is strapped onto the cushion with two Velcro straps.

The key feature of this design is the T-bar since it allows one arm cushion to be used for all exercises. The wrist flexion/extension and elbow flexion/extension arm-to-motor couplings were designed to put the forearm axis the same distance away from the target plane. The T-bar extends out to this distance (there is a stop on its back end) so the armrest lines up with the forearm axis.

REFERENCES

[1] B. D. Adelstein, M. J. Rosen, and M.L. Aisen. Differential Diagnosis of Pathological Tremors According to Mechanical Load Repsonse. Proceedings, RESNA 10th Annual Conference, San Jose California, 1987.

[2] J. Jankovic and S. Fahn. Physilogical and Pathological Tremors: Diagnosis, Mechanism and Management. Annals of Internal Medicine, Vol. 93, No. 3, Sept. 1980.

[3] R. R. Young. Physiological and enhanced physiological tremor; in Movement Disorders: Tremor, ed. L. J. Findley and R. Capildeo, (Oxford University Press, New York 1984)

[4] V. P. Pardoel, B. D. Adelstein, J. A. Romero and M. J. Rosen. Objective Correlates of Clinical Judgement of Tremor Severity. Proceedings, 6th Annual Conference on Rehabilitation Engineering, San Diego, California 1983.

[5] M. J. Rosen and J. Romero. A system for Objective Assessment of Pathological Tremors. Veterans Administraion grant application, October 1987.

[6] Theresa M. Loney. Master's Thesis: An Impedance Simulator for the Assessment and Diagnosis of Human Limb Tremor, (Massachusetts Institute of Technology, 1990)

[7] L. J. Findley and R. Capildeo. Classification of tremor; in Movement Disorders: Tremor, ed. L. J. Findley and R. Capildeo, (Oxford University Press, New York 1984)

ACKNOWLEDGEMENT

This work is funded by the Veterans Administration via a contract from the Brockton/West Roxbury VAMC. The co-investigators at that institution are Drs. Jorge Romero, Robert Young and Alan Wiegner.

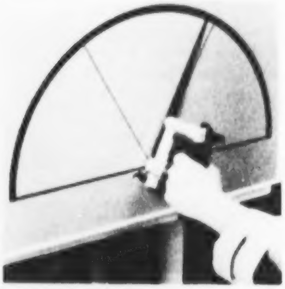


Figure 2. Assessment of Pronation/Supination

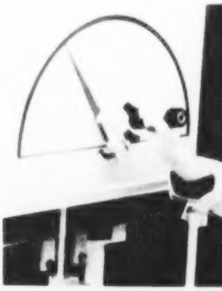


Figure 3. Assessment of Wrist Flexion/Extension

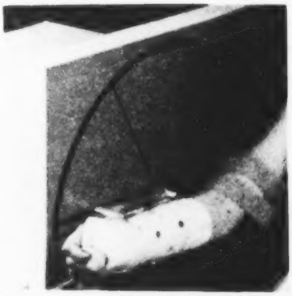
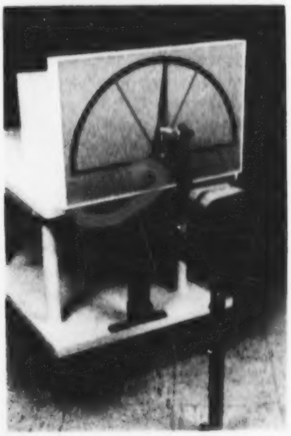


Figure 4. Assessment of Elbow Flexion/Extension



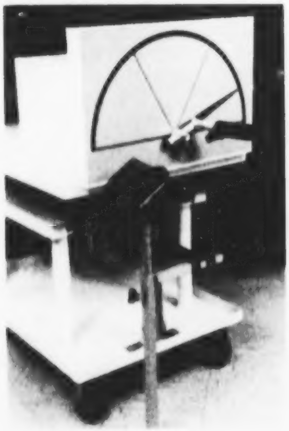


Figure 5. (left) The Arm Restraint for Forearm Pronation/Supination.

Figure 6. (right) The Arm Restraint for Wrist Flexion/Extension.

ADDRESS

Diane Brongo, Room 3-137,
MIT, 77 Massachusetts Avenue
Cambridge, MA 02139

The Polhemus Isotrack as an Assessment Tool for Cerebral Palsy

James W. Fee, Jr. and James W. Labuzzetta
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

ABSTRACT

The objective of this study was to develop a computerized pursuit tracking system for the quantification of upper limb dysfunction seen in patients with cerebral palsy. The tracking system employed a magnetic sensing device produced by Polhemus Navigation System Corporation in conjunction with a 286 personal computer. Forearm position, resulting from flexion and extension of the elbow, was recorded as the subjects attempted to follow a series of computer generated targets. Measurements of a control group of healthy subjects and a cerebral palsied group were obtained. Statistically significant differences ($p<.01$) existed between the two groups for several mathematically extracted attributes of the tracking data.

BACKGROUND

Cerebral palsy is a nonspecific term used to describe a persistent qualitative motor disorder caused by nonprogressive damage to the central nervous system. A predominant clinical manifestation of the disorder is athetosis, which is characterized by slow, writhing, involuntary movements which lack fixed amplitude, rhythmicity or direction. Several recent investigations into the quantification of athetotic movements[1,2,3] have utilized electric goniometers placed at the elbow joint to record arm movement during pursuit tracking tasks. The findings of these investigations suggest that sufficient differences exist between normal and cerebral palsied subjects regarding their ability to perform a tracking task and that frequency analysis using a fast fourier transformation is an important method of identifying these differences. The present study was undertaken to determine if a pursuit tracking system utilizing a magnetic sensing device in place of a goniometer could confirm and enhance the results of the earlier studies.

The magnetic sensing device, which utilizes the principle of low-frequency magnetic field technology for the determination of the position and orientation of a sensor relative to a source, is a subsystem of a packaged system manufactured by VPL Research. The system combines their Data Glove with the 3SPACE Isotrak by Polhemus Navigational Science. The authors interfaced the Isotrak subsystem with a 286 personal computer and an author written control software package.

RESEARCH QUESTION

The present study was undertaken to determine if a pursuit tracking system utilizing the Polhemus Isotrak could confirm and enhance the results of earlier studies done with electric goniometers, which demonstated differences in the tracking ability of normal healthy subjects and subjects with cerebral palsy.

METHOD

Experimental Setup-The tracking system was configured to calculate the angle between the magnetic sensor attached to the subject's forearm and the table surface on which the magnetic source was placed. Upper arm motion was restricted with an adjustable brace. The brace held the upper arm at a 45 degree angle with the table's surface and allowed unrestricted flexion and extension of the elbow. A series of computer generated targets were presented to each subject. The targets, in the form of highlighted bars, moved up and down on the CRT screen. Next to each target bar was a highlighted tracker bar whose up and down motion was controlled by the magnitude of the angle between the forearm and the table's surface. As a target moved on the screen a subject flexed or extended his/her elbow so the tracker bar mimiced the motion of the target bar. The target position and the angle were recorded at 60 Hz and stored in a computer file.

Data Collection- Arm position data for 36 normal subjects (mean age = 14.0 yrs) and 18 cerebral palsied subjects (mean age = 14.1 yrs) was collected. The subjects were presented with 7 separate tracking tasks:

1. Tracking a 0.5 hertz sinusoidal target
2. Tracking a 1.0 hertz sinusoidal target
3. Tracking a randomly generated target
4. Flexing and extending the elbow as fast possible,"freewheeling"
5. Holding the forearm as still as possible
6. Tracking a sinusoidal target at a frequency chosen by the tester
7. Tracking a sinusoidal target at a second frequency chosen by the tester

In each case the tracking task lasted 16 seconds and the test was administered by a certified Physical Therapist.

Data Analysis- The recorded angle data of the seven separate tasks for each subject were analyzed by applying a fast Fourier transformation. The transformation produced power spectral density (PSD) curves showing frequency and amplitude distributions in the range from 0 to 30 Hertz. Examples of PSD curves for a normal control subject and a cerebral palsied subject are shown in Figure 1.

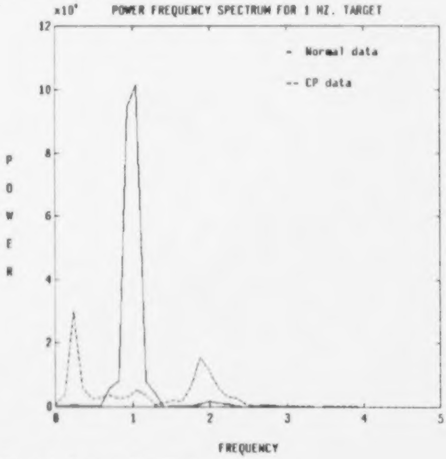


Figure 1. Power vs. Frequency

In order to make comparisons between the normal control group and the cerebral palsied group, five attributes were determined for each individual PSD curve. These five attributes were:

Total Power- Obtained by integrated the frequency spectrum over the entire range (0 - 30 hertz).

Frequency at Maximum Power- The frequency at which the spectral density curve reaches its maximum value.

Maximum Power- The value of power at the highest point on the spectral density curve.

Moment of Distribution about Maximum Power- Obtained by summing the power spectral values over the entire range with each value multiplied by the difference between its frequency and the frequency at Maximum Power.

Partial Power- The percentage of total power under the curve between 0.3 and 0.6 hz.

The mean values of these attributes were calculated for the seven separate tasks within each group and compared using the "Separate" t-Test

RESULTS

Comparing the two groups using the mean values of the five described attributes resulted in the identification of several statistically significant($p<.01$) differences. In general we found that the total powers generated by the subjects within the normal group were greater than the total powers generated by the cerebral palsy subjects for the 0.1, 0.5, and 1.0 Hz tracking tasks and the "freewheeling" task. Additionally it was found that the total powers generated while "holding still" by the subjects within the normal group were less than the total powers generated by the cerebral palsy subjects. The "freewheeling" data was also significant for the frequency of maximum power, which is a measurement of the speed at which the arm flexed and extended. The mean frequency of the control group and the cerebral palsy group were 2.28 Hz and 0.69 Hz, respectively. This means that the cerebral palsy subjects flexed and extended their arms at approximately one third the speed of the normals. Even though the above results were statistically significant, overlap of data between the normals and the cerebral palsied subjects would prevent a diagnosis based on any of these attributes..

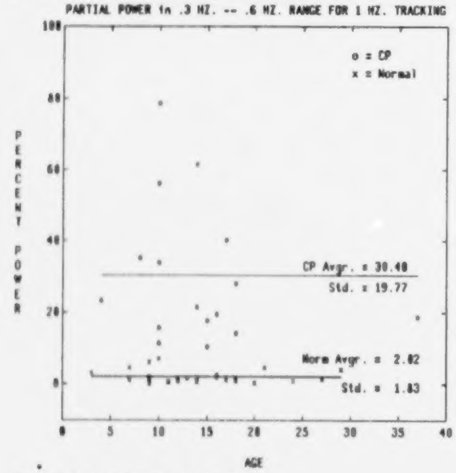


Figure 2. Parital Power for 1.0 Hz. Tracking

The most interesting result we found had to do with the power generated in the 0.3 to 0.6 Hz range when performing a tracking task with a target moving at 1.0 Hz. This range was selected for analysis based on Neilson's findings that the athetotic arm is underdamped and has a rhythmical oscillation at about 0.3-0.6 Hz.[1] The mean partial power of the cerebral palsy group was greater than the control group's. The difference was statistically significant($p<.01$) and a graph of the data, Figure 2, revealed a distinct and complete separation of two groups in this study

DISCUSSION

The results of our study are consistent with those of others who have attempted to quantify arm movements in cerebral palsy. We have found, in agreement with Neilson[1], that the percent of power in the 0.3 to 0.6 Hz. range is higher in our CP subject group than in the normal subject group. In addition we found that this difference seems to be greater when the subject is attempting to track a target than when he is attempting to hold still or move as fast as he can.

If the higher powers in this frequency range are do to an athetotic tremor, our data suggest that this tremor may be aggravated by attention to coordination

ACKNOWLEDGEMENT

Funding for this research was provided by the Nemours Foundation.

REFERENCES

1. Neilson, Peter, D., "Measurement of Involuntary Arm Movement in Athetotic Patients", J of Neurol., Neurosurg. and Psy. 1974, Vol 37, 171-177.
2. Neilson, Peter, D., "Voluntary Control of Arm Movement in Athetotic Patients", J of Neurol., Neurosurg. and Psy. 19,4, Vol 37, 162-170
3. Reddihough, Dinah, et. el., "Objective Test of the Quality of Motor Function of Children With Cerebral Palsy: Preliminary Study", Develop. Med and Child Neuro. 1990, Vol 32, 902-909.

James W. Fee, Jr. and James W. Labuzzetta
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
P. O. Box 269
Wilmington, DE 19899
Phone: (302)651-6830

Physical Activity Profiles: Using the Actimeter for Vocational Assessment

John R. LaCourse and Steven C. Koenig
Electrical and Computer Engineering Department
Kingsbury Hall
University of New Hampshire
Durham, New Hampshire USA

Abstract

The Actimeter is a device that measures and records gross human body movements. The data obtained from the Actimeter are used to establish body position profiles of able-bodied individuals partaking in a variety of occupations. These profiles are then used to aid vocational rehabilitation counselors with the placement of disable-bodied persons into jobs they are physically capable of performing. The analysis of preliminary data obtained from Actimeter tests indicate that the system is approximately 75 percent accurate.

Introduction

Recently, Rogan and Hagner [1] discussed the need for improvement in the area of effective and efficient job placement for the disable-bodied population. They identified the current criteria for vocational evaluation as; "(a) describing an individual by his/her functioning needs, (b) specifying the outcomes to be achieved through rehabilitation , and (c) identifying the interventions and services required to achieve those outcomes." They assert that several problems characterize the "traditional evaluation" process. These included "traditional vocational evaluations typically occurring in artificial, simulated environments", and that "the most fair, reliable, and useful way to evaluate an individual with severe disabilities is within the actual work setting using materials that are naturally present."

Statement of Problem

The successful placement of disable-bodied individuals into jobs best suited for them is one of the main goals of vocational rehabilitation. The long range goal of the actimeter project is to produce a reliable system that will provide rehabilitation counselors with an additional evaluation tool enabling them to place their clients into jobs they are physically capable of performing. In all, the research question is can we build a device that will satisfy the criteria defined by Rogan and Hagner.

Rationale

The Actimeter will be used to establish body position profiles of able-bodied individuals for an assortment of occupations. This information will then be stored in data bases within a computer analysis program. The vocational rehabilitation counselors would use this program to match their clients abilities to occupations they are physically capable of performing. The computer analysis program would, in effect, provide the counselor with data for an objective analysis. These data would supplement the current evaluation process enhancing the quality of services being rendered.

Design and Development

The actimeter system is comprised of several different components [2]. An Actimeter, the actual data acquisition unit, contains the microcontroller (Intel 87C51) used to measure and record data during the test period. The Actimeter is connected to a cable system containing six mercury switches that detect the various body positions at 45 degree intervals. The sensors are attached to an undergarment suit, via velcro stirps, worn by the test subjects. The sensors are placed on the head, side, back, upper arm, and upper and lower leg (see figure 1).

The information collected by the Actimeter is downloaded for analysis into either a digital display unit or a personal computer. The digital display unit displays the information on a LCD. The personal computer receives the data from the Actimeter through an interface. This data may then be stored in a data file. The information stored in a data file after an actimeter test may be observed and analyzed using a computer analysis program. This program allows the user several different options to be selected from the main program menu. These options include tabular displayed results, bar and line graphs, and an error analysis.

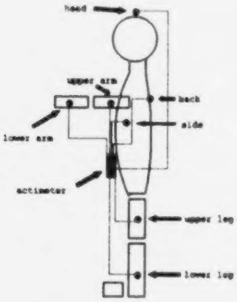


Figure 1: Actimeter System.

Evaluation

Three sets of testing were performed on able-bodied individuals to determine the reliability and feasibility of the actimeter system. The first tests were designed to establish a testing procedure protocol and to receive feedback from the test subjects regarding whether they found the system obtrusive. The test subjects were required to wear the actimeter system for eight hours during their normal workday. The second set of testing was done to determine the capabilities and limitations of the actimeter system. Five subjects performed a sequence of different tests that included system accuracy, range of freedom, sensor hysteresis, system response to varying speeds, and alternative sensor placement systems. The third set of tests involve five students, who each wore the actimeter system five consecutive school days, eight hours each day. Their body position profiles were observed and analyzed to determine common behavioral patterns.

Discussion

Initial testing was designed to establish a testing protocol. Based upon feedback received from the test subjects, the actimeter system was not obtrusive, as it did not inhibit the subjects' body motion. The data retrieved from the Actimeter were compared to written observations made by the test subjects regarding the types of activities they were engaged in during the testing period. These data revealed that the data collected by the Actimeter matched the types of body positions assumed by the test subjects.

The second set of testing was done to determine how reliable the actimeter system was and what it's capabilities were. A range of freedom test determined that any body positions assumed by a test subject in the vertical plane were not altered by movement, for that particular position, in the horizontal plane. Hysteresis testing defined the capture zones of the mercury sensors for each of the body positions. Additionally there was some hysteresis associated with the sensors, approximately plus or minus one degree for each position. System response to varying speeds defined the amount of 'jitter' inherent in the system. Slow and normal variation speeds showed no traces of 'jitter'; however, for fast variation speeds some 'jitter' was observed. Finally, from the first set of test results it was observed that there may have been error in the system due to the undergarment suit. Therefore, alternative sensor placement systems were tested for accuracy. The two additional systems were a restrictive undergarment suit and a skin attached sensor system. The results of this testing showed that the restrictive undergarment suit would be the most accurate system.

The last set of testing was performed by five students. The results of this testing (see figure 2) showed that there were common patterns and trends regarding the types of body positions the students assumed. The numbers along the horizontal axis in figure 2 represent the different body positions the actimeter system can detect. For example, the most commonly occurring positions were numbers 24, 22, 21, and 12, which are 'Head 0', 'Arm 0', 'Arm 45', and 'Sit 0, Leg 0'.

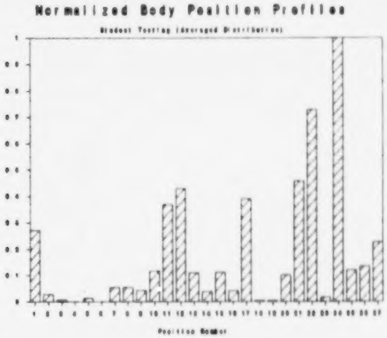


Figure 2: Student Testing.

The results of these three sets of testing showed that there was a substantial amount of error in the system, approximately 25 percent. However, observations and feedback from test subjects demonstrated that with improvements to the existing system a clinically feasible unit could be achieved. The greatest sources of error were due to the undergarment suit, mercury sensors, and sampling rate. The next version of the actimeter system will include a restrictive undergarment suit, shown to be the most accurate, a one or two second sampling rate, and larger mercury sensors. Additionally, two sided body movement and a lower arm sensor will be incorporated into the system. Once completed, further feasibility testing will be performed.

Acknowledgment

This work is currently being supported by the Social Security Administration.

References

[1] P. Rogan and D. Hagner, "Vocational Evaluation in Supported Employment," *Journal of Rehabilitation*, pp. 45-50, March 1990.

[2] S.C. Koenig, "Analysis of Human Functional Mobility Via the Actimeter," *Master Thesis,* December 1990.

John R. LaCourse
Dept. of Comp. and Elec. Eng.
Kingsbury Hall
Univ. of New Hampshire
Durham, NH 03824
(603)-862-1324

10.1

POWER MOBILITY: A PARENTS VIEW

PHILIP A. WHITE

Abstract

This paper deals with attempts to get Rachel, my daughter, a practical power mobility solution through 'normal' channels and the final chair that I created. I will discuss the design, development and implementation of a unique power mobility system that my daughter could use, given her severe limitations, both mentally and physically.

Background

My daughter, Rachel, has cerebral palsy. She is athetoid and exhibits strong muscle tone. She cannot hold her head up for an extended period of time. Her hands are of very little use to her. She cannot cross mid-line, and any attempt to extend her arms puts her entire body into extension. She has a cognitive diagnosis of severe and profound retardation.

Because of my daughter's severe cerbral palsy and her "severe and profound mental retardation" label, professionals did not believe she could acquire the motor skills needed to use powered mobility. My wife and I believed she would, because Rachel has a strong desire to participate in life and is willing to work hard at tasks that are presented to her.

To give our daughter a chance to demonstrate she could develop the skills needed to control a power wheelchair, we adapted a "TOMY ARMSTRONG" toy robot. This is a small motorized childs toy that has a joystick control. I build a seating system and enlarged the joystick with a tennis ball. The seat contained a high back with, lateral supports, seat belt, trunk support strap, and a head rest. There were also straps to hold her feet in place. Rachel learned to drive this device in one sitting. She developed two methods of operating the controls. To go backward, Rachel hooked the joy stick in her hand and pulled it toward herself using her back thrust. When she wished to go forward, she sould lean forward and push the stick with her forehead. She learned very quickly how to use a combination of these two methods to get about anywhere that "READY," as we called the toy, would go.

Neither of these methods of control were acceptable to her physical therapist or her occupational therapist. They insisted that Rachel was stimulating primitive reflexes that they thought were in her best interest to suppress. Nevertheless, READY served the purpose that I had designed it for. First, there was now no doublt in my mind and in my wife's mind that Rachel could handle power mobility. Second, we learned that she would probably not be able to control the system with her fingers.

So with hope, I set out for the local developmental disabilities clinic to see what they could do about a real power mobility system. My wife and I had difficulty convincing the professional staff that Rachel was a candidate for mobility technology.

We had to arrange a demonstration of Rachel's competence. Only after she drove her toy around for them, did they even concede that she was a possible condidate for power mobility. My wife and I had so many misgivings about the negative attitude of the clinicians that we decided to take the situation into our own hands. Thus we set out on the adventure of creating a good system for our daughter ourselves.

Objective

We first defined what we thought was needed in a seating system for Rachel. Our criteria included the followin: 1. There should be only one seating system for both manual and power, since the chair needed to be adjusted every six months or so. 2. My wife, who is 5 feet tall, needed to be able to transfer the seating from manual to power. 3. The power system needed to move slow so Rachel could control it. 4. Yet it needed as well to be capable of going just about anywhere a child her age would want to go: grass, gravel, reasonable hills, door thresholds, curved street curbs, and over just about any small obstacle.

Methods/Approach

The methods I used to determine what could be purchased and what needed to be created involved basic trial and error. Through the help of local dealers, I evaluated many different powered wheelchair systems. Physics text books from local libraries provided the needed information on such subjects as how casters track, different wheel drive mechanisms, and information about front versus rear wheel drives.

Results

The only power base that seemed to fulfill our needs was the Inva-Care Arrow Xt, which was then a prototype 'F=R' chip in the 1551 switch controller. With this base and Rachel's current manual seating system a Safety Travel Chair (STC), the basic pieces were in place to create something practical which she could control. The Arrow XT would provide the power plant, the Travel Chair, the seating system, and the 1551, the electronic control. The items which still needed to be created included the method of attaching the Travel Chair to the Arrow XT, and a switch control system for Rachel to use to control the chair. With a little help from the rehabilitation unit of a local hospital, all these pieces were put together to meet the original criteria. Funding was secured through the insurance plan provided by my employer.

I built an interface that usees a single lever to attach the Travel Chair to the Arrow XT. I also created a new front wheel system for the STC that could be removed using a lever screw. To change from manual to power the STC was placed on the power base by removing the rear wheels, the same way the chair is placed in a car. The rear was locked in place using a lever in the back.

The front and rear wheels are removed and the switches are put in place. Turn on the Arrow XT and off she goes. Transferring the system from power to manual or back took about the same amount of time as it takes to take Rachel in or out of the seating system. Transfers were done with Rachel in the chair.

Rachel controlled the chair by activating four switches which were mounted around her head. Two of the four switches stored on the STC, and could be used for activating other devices. The other two stayed with the power base. The switches on the STC were mounted on a hibge that allowed them to swing from behind the chair into place placing a switch on each side of her head, around the temples. These switches controlled left and right movement of the chair. The front and back switches were mounted on one piece that slid into a groove, made from a drawer slide, attached to the back of the STC. The front switch was mounted such that Rachel pressed it with her forehead. The rear switch was behind her head such that she had to push her head straight back in order to activate it. Above her head was a small plate that rested lightly on top of her head. This plate, attached to the bar that held the switches, was mounted on a parallel arm mechanism. If Rachel moved her head up or down this system would cause the switches to follow her head movement.

The STC was mounted on the Arrow XT so that the drive wheels were in front, thus pulling the casters behind. With this arangement Rachel was able to go almost anywhere the other children could go. One of her favorite activities was to drive the chair half way over the street curb and then press one of the side switches. This would cause the chair to spin around in a circle going up and down the curb. The hill next to out house which had a slope rangeing from 15 to 20 degrees was not a problem under normal conditions.

Discussion

Rachel is a child whose severe physical limitations impact her ability to function in daily life. When we see a child like this, we must not arbitrarily eliminate them as a candidate for power mobility. I feel that this opportunity must be presented in steps that can help the child grow. These steps must not be overwhelming but yet must chalenge the child to use all of their resources.

When Rachel was presented with the TOMY robot she learned and adapted, using the skills she had available to her. This toy allowed her to explore and experience a new world of independent mobility. It allowed her to to do things she had never been able to do before, like being naughty. She cherished the opportunity to empty the books from shelves in her room. She also learned the physical power that she now had at her disposal. That if she ran into things they could break, or that she could now run over her brothers as they had done to her many times. Yet on the toy she could not do any real damage,to either herself or what she hit. Once those lessons of independence were learned she was ready for the next step, a system that was fully functional. When she started driving the Arrow XT she already understood it's potential power and was very careful to avoid any possible collisions.

Developing a functional power system for Rachel presented many problems. The first consideration was her method of control. We tried many different systems: standard joysticks, sip and puff, chin and cheek joysticks and so forth. The best method appeared to be to use her head movement. Once the chair was created she showed a quick and marked improvement in her head control.

In creating the halo switch system, Rachel's inability to hold her head in a stable position without having something to rest it upon became the biggest problem. To slove this problem I designed a new head rest that better stablized her head laterally. In this new design I was able to take advantage of the newly found head control that operation of the chair had given her. The prooblem of the back extension was solved by making the front and rear swithces float up and down with her head movement. Without this feature, sometimes the switch was on her nose and other times it was above her head. The floating switches also allowed her to pull her head forward out of the halo if she desired. The rear switch was placed behind her head carefully so that she could not activate it using her back thrust. If she did try to extend pressing backwards, the switches just floated right up with her head. She had to push her head backwards without moving her shoulders and without raising her chin. All of the protoype switches were built by myself. The final system used four mounting switches, from Don Johnston Developmental Equippment, mounted on quarter inch rod.

I decided to mount the seat with the drive wheels in front. This arrangement solved two problems. First the total length could be reduced because the foot rests did not need extra space to clear the casters. Secondly when using non-proportional control the chair's movements followed the switch indications more accurately. When the drive wheels were in back and the forward switch was pressed the chair would turn slightly in the direction that the casters were facing before going straight. This presented a control problem for Rachel. With front wheel drive this did not occur.

The final step was to mount the STC to the Arrow XT. Which was accomplished by designing a metal mount and locking the system using the existing features of both the chair and base.

After completing the system Rachel had a device at her disposal that made an enormous impact on the quality of her life. The technology and resources are available to make this possible for many other children. We must continue to be inovative in our possible solutions before we give up.

Acknowledgements

I would like to acknowledge the help offered by Patricia Barr, Rehabilitation Engineer for the University of Iowa Hospital Schools, Division of Developmental Disabilities, and the help of Roni Burns then of Homedco, Des Moines Iowa.

Phil White
1655 17th Ave.
Marion, Iowa 52302

10.2

THE EFFECT OF TRANSDUCER CURVATURE ON INTERFACE PRESSURE READINGS

Calvin L. Guthrie
Roho Incorporated
Belleville, IL

INTRODUCTION

Flexible air inflated transducer's, such as those supplied with the Oxford Pressure Monitor (OPM), accuracy change dramatically when curved. To assess the interface pressure produced when a person is seated on a cushion the curvature of the transducer must be known. While developing laboratory tests to measure the readout pressure verses the radius of curvature is fairly simple and straight forward, measuring the curvature when the transducer is between two compliant surfaces, body and cushion, is extremely difficult. Therefore, to compare different cushions having different displacement characteristics when supporting different people without accounting for the transducer curvature is a meaningless activity.

BACKGROUND

Attempting to document all of the sources for error in interface pressure measurements, soon produces a large number of inter-related factors that are difficult if not impossible to measure separately. Three major categories for error might be set out as the transducers and their associated electronics, clinical technique, and the interface artifact. Transducer types can, in part, be divided into rigid and flexible, thick verses thin, flexible air inflated with and without electrical contacts. Size is an important factor and with electrical contacts, the width of the contacts, location and spacing within the transducer influence accuracy. Single cell verses matrix types can also be a factor. With clinical techniques some of the factors are how to locate data sites, can the transducer be reproducibly located by different clinicians, and what kinds of quality assurance measures can be applied to the results. Interface artifacts include ease of deformation of the support surface, displacement distance, surface tension, coefficient of friction, muscle bulk, age, degree of innervation, state of dehydration, etc. The reader can continue the process of identification of sources for error.

A review of the literature revealed several things. Most of the studies published expect data from healthy, able volunteers to be applicable to the disabled with multiple health compromises. Few researchers have questioned whether the instrumentation they are using is accurate in any state, let alone equally accurate across the variety of support surfaces tested. Even fewer questioned if the transducer itself is a major artifact in the data obtained. Of those researchers that did calibrate their transducers only a couple were found to have tested the transducers in anything but the flat state.

Reger et. al.[5] tested the OPM, TIRR Pressure Evaluator Pad and the Scimedics pressure gauge for correlation to an externally measured pressure or calculated physical load in both the flat and curved states. The flat test was similar to that of Reddy et. al.[4] and generally follow the calibration test described by Talley in the instructions for the OPM. The transducer is calibrated by being placed between two flat soft surfaces with a known external pressure applied. The applied pressure is then compared to the transducer readout. Reger found an excellent comparison for all three transducers in this state. However, when he used a bowling ball on foam for the externally applied load the correlation between the calculated load and the transducer readout ranged from 15% below to 50% above that of the transducer readout. Reddy attributes this discrepancy to edge stresses developed by the gap created because of the finite thickness of the transducer. Reger probably more adequately describes the discrepancy as the support surface's inability to envelope around the transducer. Support surface enveloping being a term described at length by William Chow.[1]

If Reger and Reddy are right, then why do they report such good correlation when the same transducers on the same poor enveloping surface types are used flat? Reddy demonstrated good correlation of the Scimedics PEP to the invasive wick catheter method under the thigh. This area is almost the same as the flat laboratory test and is not presenting the transducer with the small radius curve of an underlying bony prominence. It would be interesting to see the results if Reddy had tried the same experiment in a location with high incidence of pressure sore formation.

Ferguson-Pell et. al.[2] recognized the problem of curved surfaces limiting the size of rigid strain gauge transducers and that there is a significant contribution in the total applied load from in-plane stresses. In particular he states, "Pressure gradients can only be characterized with transducers having dimensions considerably less than the minimum radius of curvature of the body area under investigation."

Levine and Kett[3] add that interface pressure measurements do not account for body tissue mechanical properties which not only vary between individuals but by location within an individual. Muscle bulk, degree of innervation, wellness, mental status, and age may also be unaccounted contributors.

Clearly others have recognized the problem and Reddy's statement that transducer performance is highly dependent on the properties of interface materials is exactly true.

EFFECT OF TRANSDUCER CURVATURE

RESEARCH QUESTION

In an effort to show the effect of transducer curvature on the pressure readout of the OPM seven different support surfaces were tested using a curved surface indentor. The seven surfaces chosen were an attempt to have a variety of surfaces similar to market availability and provide a range of deformability.

METHODS

The indentor was modeled after the Ischial Tuberosity of a skeletal pelvis but simplified from the complex radii of the I.T. The end of the indentor in contact with the transducer is approximately 2.5 cm in diameter with a spherical radius of 2.5 cm. While the reduction in complexity aids the ability to test the idea it severely limits the ability to compare the data generated to that generated using live disabled persons. The weight of the indentor was approximately 2.27 Kg.

The indentor was positioned so the center of the indentor was centered on the transducer cell. Several readings were taken to insure centering and a maximum pressure were obtained.

The calculated load of the indentor is 145 gm/cm^2 or 107 mm Hg. If the transducer is completely enveloped by the support surface the instrument readout should be close to the calculated load. If there is less than complete enveloping then the contact area will be smaller increasing the readout.

RESULTS

INDENTOR WITH SINGLE CELL TRANSDUCER

Surface	mm Hg
office chair	286
Action Products Flotation Pad	256
Varilite	251
2" Alimed foam	238
Jay Active	233
2 density molded foam	197
Roho High Profile	069

DISCUSSION

Using the regular form of the indentor the OPM Single Cell transducer should have given the same reading on all surfaces if they all enveloped the transducer equally bending it around the indentor. The order of the readouts is however about as would be predicted from visual inspection of how the surfaces deformed around the indentor. It should be noted the 2 density molded foam cushion has a top layer of extremely soft flexible foam over a core of more dense material. The indentor did not appear to weigh enough to penetrate to the dense core. The Roho cushion reading is very low because the air cells adjacent to the one the transducer was placed on picked up the sides of the indentor as it sank into the cushion greatly increasing the surface area supporting the load.

The curvature of the transducer as measured here by the difference in deformation characteristic of the support surface is significant. How much more change in readout is possible when both sides of the interface are deformable is not known nor is it usefully measurable. Meaningful comparisons of cushions are not possible with flexible air inflated transducers.

REFERENCES

1. Chow WW, Mechanical Properties of Gels and other Materials with Respect to their use in Pads Transmitting Forces to the Human Body, Technical Report No. 13, Univ. MI, Dept. Phys Med & Rehab, 1974

2. Ferguson-Pell MW, Bell F, Evans JH, Interface Pressure Sensors: Existing Devices, Their Suitability and Limitations, in Bedsore Biomechanics, ed. Kenedi RM, Cowden JM, University Park Press, Baltimore 1976

3. Levine, SP, Kett RL, Tissue Shape and Deformation as a Characterization of the Seating Surface, IEEE Eng in Med & Biol Soc 11th Annual Int Conf pg 851-852, 1989

4. Reddy NP, Palmieri V, Cochran GVB, Evaluation of Transducer Performance for Buttock-Cushion Interface Pressure Measurements, J Rehab Res & Dev 21:1, 43-50,1984

5. Reger SI, McGovern TF, Chung KC, Stewart TP, Correlation of Transducer Systems for Monitoring Tissue Interface Pressure, J Clin Eng 13:5, 365-370, 1988

Calvin L. Guthrie
Technical Resources Manager
Roho Incorporated
P.O. Box 658
Belleville, IL 62222

Alimed is a register trademark of Alimend Inc., Dedham, MA. Varilite is a registered trademark of Cascade Design Inc., Seattle, WA. Jay Active is a registered trademark of Jay Medical, Ltd., Boulder, CO. Roho High Profile is a registered trademark of Roho Inc., Belleville, IL.

10.3 DEVELOPMENT OF AN ANALOG CONTROLLER INTERFACE TO RELATE STEERED FRONT WHEELS TO POWERED REAR WHEELS

Frank W. Winkler, B.S.M.E., Dan Zuber, M.S.E.E.
Engineering Department, Electric Mobility Corporation
Sewell, NJ

ABSTRACT

Steering the front wheels of a powered wheelchair offers excellent directional control, and maneuverability is enhanced with the use of variable turning rates on the two wheels. By interrelating the steering control signals with control of the powered rear wheels using analog control logic, excellent steering control and ride stability can be achieved economically.

BACKGROUND

A number of configuration options exist for powered wheelchair drive systems. The most common arrangement makes use of front casters and powered rear wheels. The use of casters results in some reduction of directional control when initiating the chair movement. At start up and at low speeds this imprecise steering control can be cumbersome in tight quarters. At high speeds the presence of bumps and small obstructions in the traveled path can disturb the caster direction. The use of steerable front wheels can provide the rider with more precise steering control at both high and low speeds.

STATEMENT OF THE PROBLEM

The use of steered front wheels offer directional control advantages, while at the same time presenting some unique control considerations. The steering response characteristics need to vary with speed in order to optimize control. When indoors at low speed, precise steering control along with quick steering responsiveness and large turning angles are needed; the user needs more precise control of speed and the chair's acceleration rate should be slower. At high speeds in more open areas directional stability is of prime importance. This requires slower turning rates and smaller turning angles since even small wheel movements have a large effect on chair direction. The steering response needs more dampening and the amount of joystick movement needed to move the wheels to a given position should be increased to reduce the tendency to over control the chair.

Another consideration is stability in tight turns at high speed. The speed of the chair needs to be reduced in tight turns in order to keep the chair from rolling over. This is preferable to limiting the turning angle with speed since steering control should be given priority to best avoid obstacles. Steering responsiveness as it relates to chair speed is also dependent on the abilities and limitations of the user and must be taken into account.

DESIGN

The controller consists of three main components; two industry proven, off the shelf motor controller printed circuit boards and a custom designed control logic printed circuit board. The two motor controllers perform the functions of signal amplification and current limiting for the individual motors being controlled, one for steering and the other for drive. The Control Logic Board acts as the master control for receiving and conditioning all control inputs to determine the proper control signal outputs. Control inputs received by the Control Logic Board include joystick turn and speed signals, steering feedback potentiometer position, gear shift indicator switch position, seatlift switch position, and battery charger operation.

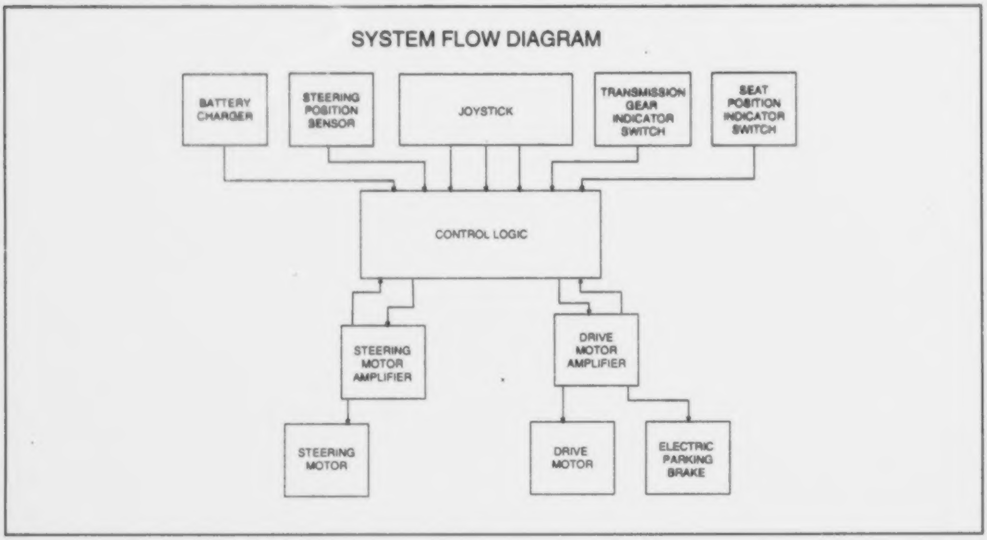

SYSTEM FLOW DIAGRAM
BATTERY CHARGER
STEERING POSITION SENSOR
JOYSTICK
TRANSMISSION GEAR INDICATOR SWITCH
SEAT POSITION INDICATOR SWITCH
CONTROL LOGIC
STEERING MOTOR AMPLIFIER
DRIVE MOTOR AMPLIFIER
STEERING MOTOR
DRIVE MOTOR
ELECTRIC PARKING BRAKE

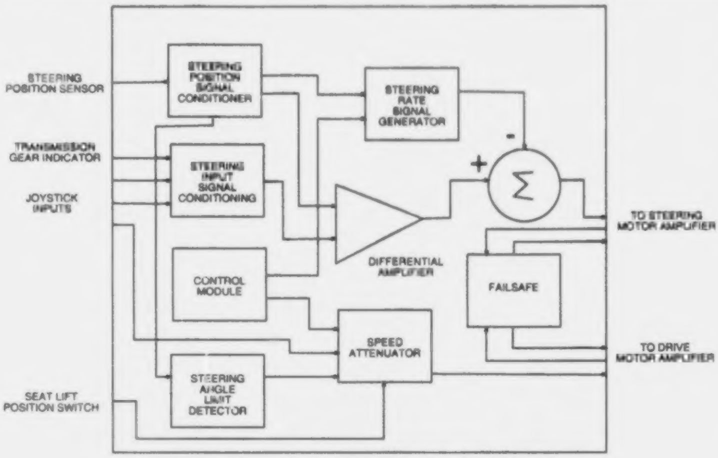
FIGURE 1

The joystick left/right signal input received by the Control Logic Board is conditioned based on the joystick speed and direction signal and the transmission gear selected. This signal is then filtered and buffered before being compared with a conditioned and properly scaled position feedback signal. The resulting error signal is amplified and sent to a summing amplifier where a signal proportional to the turning rate of the wheels is subtracted from it. The output of the summing amplifier is the low level signal used to drive the steering motor amplifier which in turn drives the steering actuator.

The joystick speed and direction signal is conditioned based on the position of the front wheels and the seat height postion. This conditioned signal instructs the drive motor amplifier to power the drive motor.

Joystick turn and speed signals are also conditioned based on the particular control module installed in the system. Small modules, which can easily be changed in the field, alter the steering responsiveness, speed and acceleration of the chair. Additional circuitry includes fail-safe logic which detects system failures and provides a controlled shutdown. Failure detection includes joystick wiring faults, joystick circuit faults, feedback potentiometer wiring faults, on board power supply faults, low battery voltage, and others. Each motor amplifier also includes its own fail-safe circuitry. Fig. 2 shows a simplified control logic diagram.

were conservatively specified in order to increase overall reliability.


STEERING POSITION SENSOR
TRANSMISSION GEAR INDICATOR
JOYSTICK INPUTS
SEAT LIFT POSITION SWITCH
STEERING POSITION SIGNAL CONDITIONER
STEERING INPUT SIGNAL CONDITIONING
CONTROL MODULE
STEERING ANGLE LIMIT DETECTOR
STEERING RATE SIGNAL GENERATOR
-
+
Σ
DIFFERENTIAL AMPLIFIER
SPEED ATTENUATOR
FAILSAFE
TO STEERING MOTOR AMPLIFIER
TO DRIVE MOTOR AMPLIFIER

CONTROL LOGIC FLOW DIAGRAM

FIGURE 2

DEVELOPMENT

The development of the Control Logic Board for this powered chair centered on refining the steering response versus speed characteristics while insuring overall stability, safety and reliability. Steering rate and angle, input dampening, chair speed and acceleration are just some of the many system parameters that had to be related to maximize user control. A large effort was put into developing a smooth and natural feel to the controls. The controls need to instill a sense of security in the user and boost his confidence in his ability to control the chair. The chair needs to move in a predictable manner under all conditions. The concern for stability and safety lead to the need to relate the various inputs so that no combinations could produce unstable operation. The system was simplified wherever possible and individual components

EVALUATION

The design goal of varying the steering characteristics as a function of chair speed in order to maximize the benefits of front wheel steering has been met. By properly selecting system parameters, steering response and user control have been optimized without compromising overall stability and safety.

The aim of achieving a system adaptable to the needs and limitations of the user has been met by the use of control modules which vary system response characteristics. These modules tailor the chair to the individual and can be easily selected and changed by the field service provider. The goal of maximizing safety and reliability was met by utilizing conservative design practices coupled with inherent safety features and extensive fail-safe circuitry to monitor critical system components.

Antiskid Wheelchair Brake Design

James J. Kauzlarich and John G. Thacker
UVa Rehabilitation Engineering Center
Charlottesville, Virginia USA

Abstract

Currently most wheelchairs have a bar/tire type parking brake, and some electric wheelchairs have dynamic brakes. The parking brake is unsatisfactory as a dynamic brake since it wears the tire severely when used as a dynamic brake.

By placing an idle wheel between the tire and the braking element and selecting a friction pad with a coefficient of friction less than that between the tire and idle wheel, the only slippage takes place at the brake pad and idle wheel, not the tire and idle wheel. The tire-idler contact is antiskid, and there is much less wear on the tire than if the tire-idler skids.

This paper presents design geometries for the concept as well as design calculations.

Background

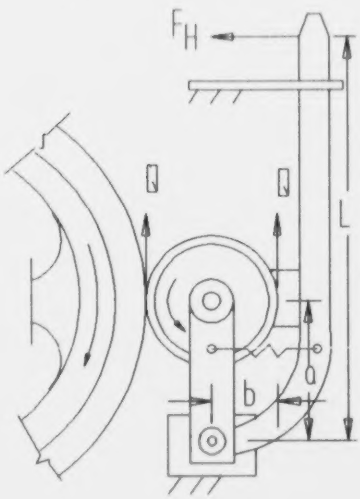
In 1986 Thacker, Seelye, and Kauzlarich presented information from a survey of wheelchair users as to the need for dynamic brakes. This survey showed that 64.8% of the respondents felt that speed limiting brakes would be helpful; the remaining respondents had no opinion. In this same paper experimental tests on commercially available bicycle type caliper brakes and hub brakes were presented. Actuating force, braking torque, and brake fade were presented. High actuating force and frequent adjustments of caliper brakes proved to be a problem. Hub brakes were recommended for adoption, but the complicated design and expense has apparently limited interest in this type of brake as they are seldom seen on wheelchairs.

Whitt and Wilson (1985) present a good introduction to dynamic brakes for bicycles. In their survey of brakes they mention the plunger brake used on early bicycles which is similar to a wheelchair parking brake of the bar/tire design. They remark that the plunger brake and the caliper rim brake are very poor in wet weather.

Problem & Rationale

Wheelchair users have indicated a need for simple brakes on wheelchairs that can be used under dynamic conditions as well as for parking. A number of brakes have evolved, essentially from bicycle designs, but nothing has been found to be outstandingly useful to the disabled in wheelchairs. Wheelchair brakes have a number of unique requirements: 1. The brakes must be lightweight and durable. 2. Quick-release hubs must not interfere with the brakes. 3. Brakes must be maintenance free., and 4. Brakes must not interfere with wheelchair folding.

Fig. 1: Antiskid Brake



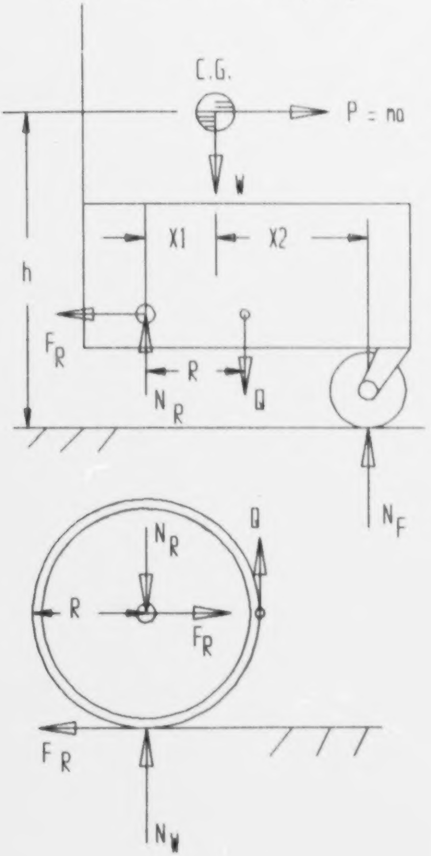
The approach used in the design of a new dynamic brake was to consider the design of the wheelchair and make as much use of the typical structure as possible. Design of a brake to fit where the parking brake is now placed would be advantageous, and it appeared that the concept of adding a simple idle wheel to the existing parking brake mechanism would result in a dynamic and parking brake, with the added advantage that the brake mechanism could be designed to have a reasonable amount of self-actuation. In order to avoid catching fingers, the lever and brake mechanism are well separated and all edges will be smooth.

Antiskid Brake Design

The new antiskid brake design is shown in Figure 1. As shown, the lever arm under a force F_H presses the brake block against the idle wheel and the idle wheel presses against the wheelchair rear tire. This action generates a force Q which slows the wheelchair. The maximum force Q_{max} depends upon the dynamic coefficient of friction at the tire-road contact. The coefficient of friction between the idle wheel and brake block is controlled by selecting an appropriate brake material, and it is desirable that this be less than the coefficient of friction between the idle wheel and tire. Thus, the idle wheel and the tire will be in antiskid operation. The antiskid operation at the tire is highly beneficial since the wear is considerably reduced over skidding wear, and the rolling coefficient of friction can be considerably higher than sliding coefficient of friction. In addition, with rolling at the idle wheel it is less likely that abrasive particles picked up by the tire will be transferred to the idle wheel; a common problem with bicycle rim brakes.

The idle wheel arm is lightly spring loaded against the brake block so that the idle wheel is inoperative when not in contact with the wheelchair rear wheel. For parking, the brake lever arm is ratcheted and can be locked in place under load. The idle wheel is assumed to be 1.5 in. in diameter and 1.0 in. wide, in steel or aluminum. The design of the idle wheel needs to be as light as possible so that it will come up to speed rapidly when placed in contact with the rear wheel of the wheelchair. There are brake block materials that are especially designed for steel or aluminum with good wet operating characteristics (See Whit and Wilson, p. 208).

Fig. 2: Wheelchair Free-Body Diagram



Model Equations

A free-body diagram of the rear wheel of the wheelchair and the rest of the wheelchair is shown on Figure 2. By applying the conditions of static equilibrium to the forces shown it is possible to write an equation for the maximum braking force Q_{max} at the brake in terms of the overall load acting at the center of gravity, dimensions of the wheelchair with respect to the center of gravity, and the coefficient of friction at the rear tire contact. The value of the dynamic coefficient of friction, μ, depends upon the tire material, where $\mu = .45$ for polyurethane, $\mu = .65$ for clay filled rubber, and $\mu = .85$ for silica filled natural rubber. The equation for Q_{max} is

$$Q_{max} = \mu W\left(\frac{x_2}{x_1+x_2+\mu h}\right) \qquad [1]$$

In addition, From Fig. 1, we have

$$F_R = Q = P \qquad [2]$$

In Eq. 1, we see that the dynamic forces acting on the wheelchair cause the maximum brake force to be substantially different from the forces that would be calculated assuming the wheelchair is stationary.

Design Calculations

The International Organization for Standardization (ISO) has experimentally determined the location of the center of gravity of user and chair (Ref. 3), and for a typical wheelchair with a weight of 55 lbs and a user having a weight of 165 lbs (Total weight of user and wheelchair is 220 lbs) the dimensions to the c.g. are

x_1 = 7 in. (0.178 m); x_2 = 8 in. (0.203 m);

$$h = 26.3 \text{ in. } (0.668 \text{ m}) \qquad [3]$$

Neglecting the rotational inertia of the wheels, the deceleration of the wheelchair due to the brake on a horizontal road according to Newton's Law is

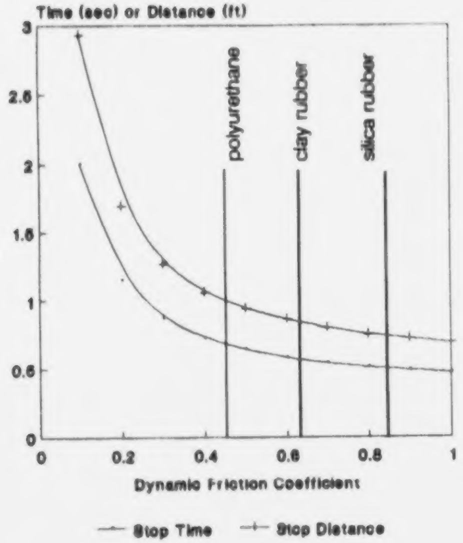
$$m\frac{d^2x}{dt^2} = F_R = Q \qquad [4]$$

From Eq. 4 and integrating once results in an equation for the time of braking as

$$t = \frac{mV_o}{Q} \qquad [5]$$

Substituting Eq. 1 and wheelchair dimensions into Eq. 5 results in the minimum time to stop from a speed of V_o = 2 mph as

Fig. 3: Antiskid Brake



$$t_{min} = 0.30 + \frac{0.17}{\mu} \quad \text{(sec)} \qquad [6]$$

The minimum stopping distance is given by

$$S_{min} = \frac{V_o\, t}{2} = 1.47\ t \quad \text{(ft)} \qquad [7]$$

The equation for the short shoe drum brake is developed in several machine design texts, e.g. Mott, p. 486, and is

$$F_H = \frac{Q\left(\frac{a}{\mu} - b\right)}{L} \qquad [8]$$

In Eq. 8 we have assumed the following dimensions for the brake shown in Fig. 1: L = 12 in., a = 3 in., and b = 3/4 in. In the case where b is as shown in Fig. 1, the drum brake is self-actuating, i.e, the force Q acts to load the brake pad against the idle wheel. This means that the user does not have to exert as much force F_H as would be necessary if the brake were not self-actuating.

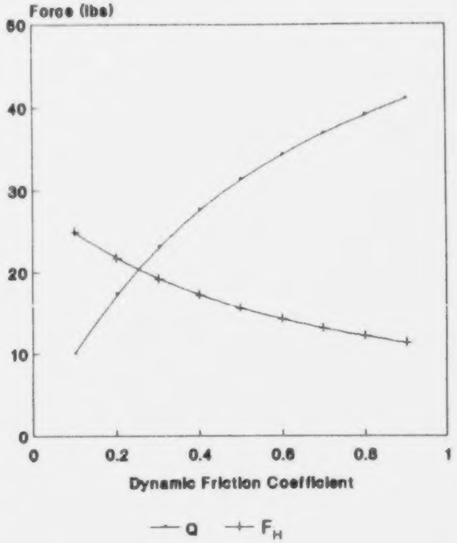
Design Results

The calculated results using Eqs. 6 and 7 are shown on Fig. 3. The operating point for three different tire materials does not show a significant advantage as far as braking is concerned. A plot of Eq. 1 and Eq. 8 is shown on Fig. 4. Here we see the advantage of using a self-acting brake, especially at high μ.

Discussion

This new antiskid dynamic brake design for wheelchairs offers significant advantages to the user over the typical parking brake currently available. The design is a self-actuating brake which minimizes the force necessary to operate the brake.

Fig. 4: Brake Loads



References

1. Thacker, Seelye and Kauzlarich, "Analysis of Manual Wheelchair Brakes," RESNA 9th Conf., 1986, pp. 290-292.
2. Whitt and Wilson, Bicycling Science, MIT Press, 1985.
3. ISO, "Determination of the Effect of Various Dummy Sizes on Wheelchair Stability," ISO/TC173/SC1/WG5, October 13, 1983.
4. Mott, Machine Elements in Mechanical Design, Merrill, 1985.

Acknowledgement

This work was supported by NIHR Grant No. G00-83-00072.

UVa Rehabilitation Engineering Center
P.O. Box 3368, University Station
Charlottesville, VA 22903

10.5

Improved Wheelchair Gearbox Efficiency

Mark R. Ford, J.G. Thacker & J.J. Kauzlarich
University of Virginia Rehabilitation Engineering Center
Charlottesville, VA 22903

Introduction

An efficient drive system in an electric wheelchair helps compensate for the limited energy supply of wet cell batteries and the time that is required to recharge them. After a recharge of the batteries, it is desired to go as long as possible before having to recharge once again. If the mechanical system in the power train is inefficient constant recharging is necessary. This paper discusses a way to extend the "on road" service time of an electric wheelchair.

Background

The drive system of an electric wheelchair consists of a permanent magnet DC motor which is controlled by a Pulse Width Modulator (PWM), a reduction gear box and a pulley-belt arrangement. The PWM is supplied by a constant twenty four volts; two twelve volt batteries. As the operator maneuvers the control stick the PWM sends varying length pulses of constant energy to the motors which determines their speed and direction. The motors are each attached to a separate gear box. The gears inside the box will reduce the rotational speed of the motor and at the same time increase its torque capability. The output shaft of each gear box is then connected to a pulley which drives the rear wheels of the chair by a belt system. Inefficiencies are found inside the gear boxes where mechanical losses occur, and in the slippage of the belt on the pulleys.

Discussion

The common practice is to use a gear box utilizing a worm and a single enveloping gear. This allows the shaft of the motor and the gear box output shaft to be at right angles to one another. Although a space saver it is not a highly efficient gearing arrangement. The worm is driven by the motor and works much the same as a power screw thread. As the worm turns it drives the gear which is partially wrapped around the worm. Because of the sliding contact between the worm and the worm gear high friction forces occur lowering the efficiency. A spur gear on the other hand consists of a small pinion and a larger gear. The pinion is driven by the motor and transmits power to the gear. Due to involute cutting of the gear teeth their is rolling friction and much less sliding friction as apposed to the constant sliding friction in the worm gear. The efficiency is therefore higher in the spur gear arrangement than that of a worm gear system[1]. If the spur gear were to be used it would not allow the chair to be folded for storage due to the shafts of the pinion and the driven gear being in a parallel line with one another. This is an important drawback for spur gearing in wheelchair design.

Assuming the necessity for compactness of wheelchair storage, another alternative is possible. Due to the relatively low volume of electric wheel chair production the gear boxes used are not specifically designed for wheelchairs. They are designed to be used at relatively high speeds. As a result the lubricant is a very viscous black grease. The entire gearbox is filled with the thick lubricant. At the low speeds that a wheelchair will be operated the grease causes a lot of drag decreasing its efficiency. A lubricant known as polytetrafluoroethyene (PTFE) is used for its ability to lubricate in unusual conditions, one of which is low speeds.

It works in much the same way as graphite. Very small solid particles slide over each other with a very low coefficient of friction. This property is ideal for the sliding motion between the teeth of the worm and the enveloping gear. As the surfaces slide past each other the PTFE particles perform as microscopic ball bearings. Small amounts of PTFE are applied only to the teeth surfaces eliminating the drag that is experienced by the total immersion of the gears in the grease.

Method

The power was measured to determine the different efficiency ratings for these different gearing possibilities. A dynamometer was used to determine the input power delivered to the system and to measure the power that was put out by the system. The efficiency was then calculated by power output divided by power input. Four different motors, all of the same type were tested to find an average efficiency rating. The one that best fit the average was then used as a constant for the two different gearbox configurations and the lubrication variation. The worm gear was tested at a constant load while varying the input voltages. Changing the amount of voltage is equivalent to the varying length pulses sent out by the Pulse Width Modulator. The speed of rotation being in direct proportion to the voltage input is a property of the DC motor and thus different input and output power values can be recorded for the various input voltages. At the same time the rotational speed at each voltage level can be used to calculate the wheelchair speed. The linear velocity of the chair can be determined from the rotational speed of the gear box output shaft and the measured radii of the two pulleys and the radius of the wheelchair wheel by the following equation:

$$VEL_{WC} = 2\pi \left[\frac{(RPM \ X \ R_{PULLEY})_{GEAR} R_{WHEEL}}{R_{WHEELPULLEY}} \right] X \ \frac{60}{1000}$$

The efficiencies found for the motor and gearbox together were then divided by the efficiency of the motor by itself for each of the corresponding voltages resulting in the gearbox efficiency. The same procedure was followed using a spur gear of approximately the same size and weight. The results of the data for both the worm gear and spur gear are shown in figure 1. The next test involved using the worm gear box and removing all the grease from inside and around the gears. The PTFE lubricant was then applied to the teeth surface and the same procedure was followed as before. The results comparing the effects of the two lubricants in the worm gear are shown in Figure 2.

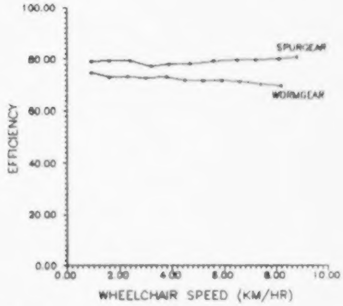


Figure 1: Efficiency vs Speed
Worm gear & Spur gear

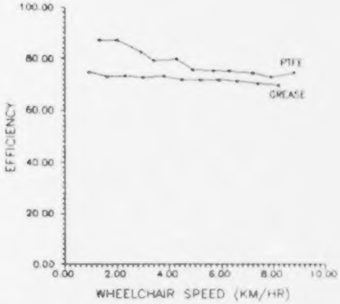


Figure 2: Efficiency vs Speed
Effect of Worm gear Lubrication

Experimental Results

As Figure 1 illustrates, the spur gear does have a nine percent average higher efficiency rating than the worm gear. Installation of spur gears of the same size and weight as the worm gears would increase the time and distance obtainable by each recharge. However, as mentioned before, using the spur gears would restrict the wheelchair's storage capabilities, due to the spur gear's characteristic of input and output shafts being parallel.

Staying with the worm gear but replacing the traditional grease lubricant with the PTFE would as illustrated in Figure 2 significantly increase the efficiency especially at the lowest speeds. The speeds, consequently, that are most frequently encountered at which turning and basic maneuvering occur. It should be noted that if the PTFE lubricant were used in the spur gear an even higher efficiency would be obtainable.

Conclusion

The experimental results for worm gear bo performance show a twelve percent increase in efficiency at the low speeds of the wheelchair and a four percent increase in efficiency at the higher speeds. This is a sufficient improvement which warrants the use of the PTFE lubricant in typical wheelchair worm gear sets.

Acknowledgement
Funding for this research was provided by the University of Virginia Rehabilitation Engineering Center under the NIDRR Grant Number H133E8003

References

[1] Mott, R.L. Machine Elements in Mechanical Design. Columbus: Charles E. Merrill Publishing Company, 1985

Prof. J.G. Thacker
UVa REC
P.O. Box 3368, Univ. St.
Charlottesville, VA 22903

10.6 AN IMPROVED DC-DC CONVERTER FOR ELECTRIC WHEELCHAIR PROPULSION

Rafael M. Iñigo, Karim T. Shafik, Collin W. Park

University of Virginia Rehabilitation Engineering Center

Charlottesville,VA 22903

Abstract

This paper describes the design, construction and testing of a pulse-width-modulated (pwm) power supply for electric wheelchairs using state-of the-art power MOSFET transistors and integrated circuits. Due to the low component count and use of n-channel power MOSFETS only, the efficiency of the circuit is extremely high, a a very important consideration for electric wheelchair power supplies. The all new pwm power supply represents a considerable improvement with respect to our previous design which used both n-channel and p-channel MOSFETS.

Background

It is well known that, in order to control the speed of an electric wheelchair, the constant dc voltage supplied by the battery must be converted to a variable magnitude dc voltage to be applied to the armature of the permanent magnet dc motors used for chair propulsion. The modern method of obtaining this variable dc voltage is by using a pulse-width-modulated (pwm) power supply, created by switching the constant dc on and off by means of power transistors. The resulting constant frequency, variable width train of pulses has an average value equal to the dc component. The waveform also contains many harmonics (ac components) that do not contribute to the motor torque. The motor efficiency is lower using the pwm supply than a pure dc voltage. However, the efficiency of the pwm supply is very high, because when the transistors are off, they do not have losses, and when they are on (and saturated, which is the case here) there only losses are due to the "on resistance", i.e. the equivalent resistance between drain and source in a power metal-oxide-semiconductor-field effect-transistor (MOSFET.) In modern Mosfets, this resistance is extremely low. In this way, circuit efficiency is optimized, an important consideration for better utilization of battery charge, and consequent improvement in hours of use between recharging and on battery life.

To avoid the anoying noise caused by the pwm at low frequencies, it is standard practice to run the converter at frequencies of 20 KHz or higher. MOSFETS are more efficient than bipolar transistors at high frequencies and their input impedance (gate impedance) is extremely high. For these reasons, MOSFETS are preferred in pwm dc-dc converter design. Until recently, it was necessary to use both n-channel and p-channel MOSFETS because the H-bridge configuration required for bidirectional operation of the motors put the gates of the two "on" transistors at very different voltage values. An all solid state dc-dc converter using both types of MOSFETS was designed constructed and tested at the University of Virginia Rehabilitation Engineering Center some years ago [1] . The efficiency of this converter was good, but it required the use of two p-channel transistors in parallel to accomodate the required operating current, because the current capacity of p-channel MOSFETS is lower than that of n-channel MOSFETS. In addition, their "on resistance" is higher than that of the n-channel device. Thus, a two p-channel combination has losses higher than double the losses of a single n-channel equivalent.

Research Objective

The objective of thisd research is to design, construct and test an efficient, compact and reliable pwm dc-dc converter with an efficiency considerably higher that that of the previous design. The basic innovation of the design consists in the use of only n-channel MOSFETS, made possible by the IR2110 integrated circuit [2]. The converter has been designed, constructed and tested, both in the bench and in an EWC.

Design and Construction Method

The all-n-channel dc-dc converter has a very low component count. It consists of the SG3731 integrated circuit (IC) pwm waveform generator, two IR2110 ICs to drive the MOSFET gates, four n-channel power MOSFETS and a few passive components (resistors and capacitors,) Fig. 1 . The H-bridge configuration allows bidirectional motor operation. The SG3731 has two pwm outputs, only one of which is active at a given time. The control signal is a voltage from -6 to +6 volts. When the input is negative, output channel B is active, and for positive input, channel A is active. The operating frequency is controlled by the RC circuit to which the input is applied and was set at 20 KHz by proper choice of C_T . Each IR2110 IC generates two pwm outputs, H and L, Fig.1, which are at the proper level to be applied to the gates of the high and low MOSFETS, respectively, as shown in the figure.

In order to drive the two motors of an electric wheelchair, the design of Fig.1 had to be doubled, i.e., two identical circuits driven by a single joystick (with two outputs) were implemented. The total number of ICs is then six (two SG3731, four IR2110) and eight MOSFETS are necessary.

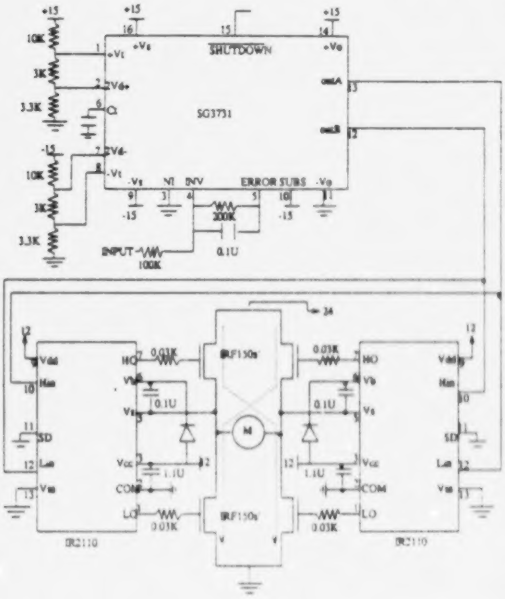


Figure 1 The all n-channel dc-dc converter

Results

The circuit was tested in the bench to check proper operation, and to determine the input-output voltage characteristic which, as shown in Fig.2 is very linear. Next, the efficiency was determined using a high precision digital power analyzer, induction dynamometer, and dynamometer digital power readout, Fig.3. Two basic tests were performed: efficiency vs armature voltage with constant torque and efficiency vs torque for constant armature voltage. The efficiency of the converter-motor combination and of the motor alone were determined, thus allowing the calculation of the converter efficiency by means of $\eta_{conv} = \eta_{tot}/\eta_{mot}$

Results are shown in Figs.4 and 5 which show converter efficiency vs armature voltage and vs torque, respectively. It can be seen that in both cases, for adequate operating conditions (i.e., armature voltage above 50% of the rated 24V and midrange torque, the converter efficiency stays above 90% . The n-channel,p-channel converter highest efficiency was about 85%. Fig.6 shows the efficiency of the "old" and the n-channel MOSFET converter+motor for constant torque (.5 Nm) and variable armature voltage. Notice the very significant improvement in efficiency of the new converter. In addition to achieving efficiencies in the mid 90% range, efficiency remains essentially constant for a wide range of armature voltage. On the other hand, the previous converter had a much lower efficiency that peaked at about 75% and decresed rapidly for lower armature voltages.

The converter was also tested in an electric wheelchair with excellent results. Tests were performed in a chair equipped with the adaptive microcomputer-based control system developed at the UVA REC [3] for flat terrain, upramp, downramp, etc. In all cases the performance of the pwm was on a par with the rest of the system.

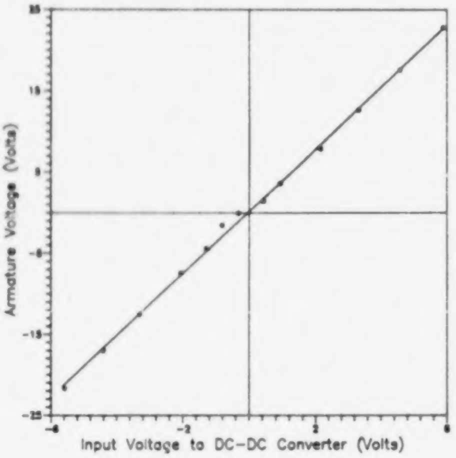


Figure 2 Converter transfer characteristic

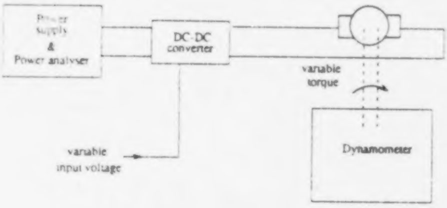


Figure 3 Measurement circuit

Discussion

It has been shown that a dc-dc converter using ICs and n-channel power MOSFETS with very low component count, and consequently high reliability, low cost and small size and weight, has an excellent efficiency and can be used for efficient electric wheelchair operation.

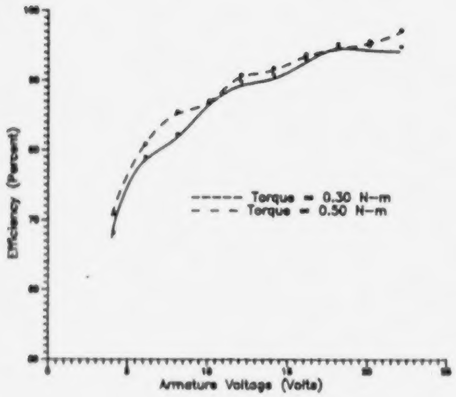


Figure 4 Efficiency vs armature voltage

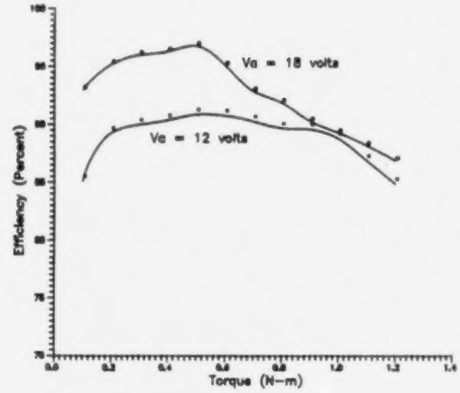


Figure 5 Efficiency vs torque

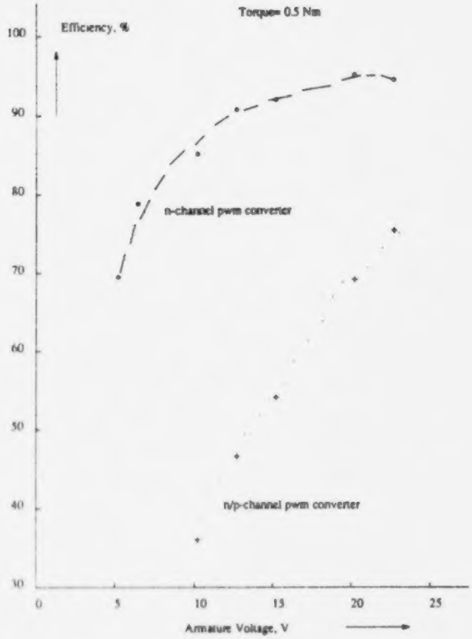


Figure 6 Comparison of two converters

Acknowledgements

The work leading to this paper was supported in part by NIDRR Grant H133E80003-90 and in part by a Grant from the Potomac Edison Company.

References

1. Iñigo,R.M. and Tsoi,D.,"Two Quadrant Feedback Dc-Dc Converter for Wheelchair Motors," *Proceedings of the Internat.Conf.on the Advance of Rehab.Enrg.*, Montreal, Canada, June 1988.
2. International Rectifier Data Sheet PD-6011B, "High Voltage MOS-Gate Driver IR2110."
3. Shafik,K.T.and Iñigo,R.M., "Implementation of an 8086-based Optimal Adaptive Controller for Electric Wheelchairs," *Proceedings of the 13th Annual RESNA Conference* ,Washington,DC, June 1990.

R.M.Inigo
UVA Rehab. Engr. Center
P.O.Box 3368, U.Station
Charlottesville,VA 22903

A NEW METHOD FOR ELECTRIC WHEELCHAIR PROPULSION

Robert Pence, Frank Churillo and Rafael M. Inigo
Rehabilitation Engineering Center
University of Virginia, Charlottesville, Virginia

ABSTRACT

Traditionally, electric wheelchair propulsion has been effected by means of permanent magnet direct current (dc) servo motors. Alternating cuurent (ac) induction motors are very reliable, unexpensive and have characteristics adequate for vehicle propulsion. However, a complex electronic circuit is required to control these motors. The recent availability of integrated circuits that perform many of the necessary functions, has simplified the design of the necessary control circuit. In this paper we decribe the design and construction of an electronic, highly integrated circuit that produces variable frequency three phase alternating current from a direct current power supply.

BACKGROUND

Electric wheelchairs have almost exclusively been driven by permanent magnet dc motors [1]. There are two basic reasons for this exclusivity: 1) this type of motor has high efficiency; and 2) it is easily controlled due to its linear torque/speed characteristic. Although other types of motors possess high efficiencies and the necessary performance characteristics, e.g. brushless dc motors and ac induction motors, they are not as easy to control as permanent magnet dc motors. The difficulty in controlling the AC induction motor is manifold: an ac wave must be produced from a dc power supply and to produce a variable speed at high efficiency, multiple variables such as the amplitude, frequency and phase of the input current must be controlled. The need to control numerous variables typically results in a complex control system that is prohibitively expensive if implemented with discrete components.

Although it may appear that permanent magnet dc motors are perfect for electric wheelchair propulsion, there are problems associated with their use. The principal problem is that these motors require a significant amount of maintenance to keep them operating efficiently. This maintenance is due to the use of mechanical commutation to control the flow of current in the armature of the motor. To produce the commutation, brushes ride on the motor commutator and as the commutator turns a spark occurs at the trailing edge of the brush [2]. Over time these sparks result in deterioration of the brushes and, eventually, the commutator itself. Hence, the need for increased maintenance.

The increased maintenance required by the permanet magnet dc motors has resulted in efforts to use other types of motors for wheelchair propulsion. One type of motor under consideration is the AC induction motor. Upon examining the ac induction motor mode of operation, it is immediately discovered that the amount of maintenance required is significantly less than that of a permanent magnet DC motor. This is because ac induction motors do not need brushes to produce an alternating current in the rotor. The c induction motor has two additional advantages over permanent magnet dc motors: 1) the power rating and mechanical speed of the motor is not limited by a mechanical commutator; and 2) they are less expensive.

The advantages that the ac induction motor possesses over the permanent magnet ac motor are encouraging. However, as discussed previously, the control circuitry for an ac induction motor is more complex than that of the permanent magnet dc motor. This factor is the main reason that ac induction motors are not widely used, but recent advances in integrated circuits my change this. The truth of this statement is indicated by the success that GM has had in incorporating ac induction motor propulsion into their electric car, the *IMPACT* [3].

DESIGN METHOD

Currently there are commercially available integrated circuits that when coupled with several power MOSFETs will produce an ac wave from a dc power supply. One such IC, the IR2110, is produced by International Rectifier. The remainder of this report will focus on the use of the IR2110 to produce a prototype motor controller for a 24 volt/24 amp ac induction motor.

Prototype motor controller

The type of motor controller designed is generally called a solid-state inverter. The inverter consists of two parts: a control portion and a power portion.

Control portion

To use an ac induction motor on an electric wheelchair, a method must be found to create a three-phase power supply. To simplify the design of the three-phase wave generator, it was decided that the motor controller would use three-phase square waves to power the motor. Therefore, complex circuitry was not needed to create a pure sine wave. This may decrease motor efficiency beyond acceptable limits. Currently we are evalauting the performance of this circuit and considering how to produce a more sinusoid-like waveform.

Circuits that use various forms of logic to produce square waves were examined to determine which type of design could provide three separate phases, while providing a means to vary the frequency over a larger range.

First, a network was constructed that provided a variable frequency, single-phase wave. This was accomplished by using an LM555 timer as a square wave oscillator. By using a 100 kΩ potentiometer in the timer circuit, the LM555 was able to produce an output that could be varied from 140 Hz to 9600 Hz.

With this variable frequency square wave, a three-phase wave was produced by using three D-Flip-Flops connected in a *Johnson Counter* configuration. In general when N D-Flip-Flops are connected as a *Johnson Counter*, a γ Hz input wave will result in N distinct output waves at $\gamma/2N$ Hz that are separated by 360°/N, e.g. with $N=3$ and $\gamma=360$ Hz then three distinct waves are output that are 120° out-of-phase with each other. To guarantee that the waves are exactly 360°/N out-of-phase, the D-Flip-Flops must be reset.

With the ability to produce a three-phase square wave from a group of logic devices, the next task is to use these low power logic level waves to produce the necessary 24 volt three-phase waves for input to the motor. This part of the inverter design is referred to as the power portion, because of its use of the IR2110s to produce a high power output from a low power logic level input. The reason for producing 24 volts ac power suppy was related to the available dc voltage (24V) from the battery.

Power Portion

The primary components of the power portion of the design are three International Rectifier IR2110 high voltage MOS gate driver chips and six IRF150 MOSFET transistors, also from International Rectifier. The MOSFETs are connected in series pairs from the 24 volt rail to ground. Each series pair provides one phase of output to the motor. By convention, the MOSFETs connected to the 24 volt rail are called the high side FETs and those connected to the ground rail are the low side FETs. The high side FETs switch 24 volts to the motor when turned on and the low side FETs switch 0 volts to the motor when turned on. Only one FET in the pair is on at any given time. Therefore, switching FETs on and off in the proper sequence will produce 0 to 24 volt square waves. With the control portion of the circuit providing three-phase squares (one phase to each FET series pair, via an IR2110, each phase of the FET drivers will provide a 24 volt square wave with each phase having a 120 degree phase shift.

The IR2110s in the circuit are used to provide the gate bias required to drive the FETs into full enhancement, i.e. with the lowest voltage drop across the drain-source terminals. The high side FETs are the primary reason for using the IR2110s instead of a generic charge injection design. This is because in order to operate the FETs in full enhancement, the gate voltage must be 10-15 volts higher than the drain voltage. On the high side, such a gate voltage is above the 24 volt rail, which is the highest voltage available in the design. The IR2110 integrates most of the functions required to drive the high side FET and it also provides the ability to drive the low side FET.[4]

A prototype inverter circuit was designed, constructed and tested. The schematics is given in Fig.1 . The IR2110 has three principal inputs (HIN, LIN and SD) and two principal outputs (HO and LO). The HO and LO outputs are connected directly to the gates of the FETs and they are in phase with the HIN and LIN inputs respectively. The HIN and LIN inputs are provided by the control portion of the design. These signals are 180° out-of-phase with each other so that either the high side or low side FET is turned on at some instance in time, but both never are on simultaneously. The SD input is also provided by the control portion of the design. When this input is held high, the HO and LO outputs are both low, thereby disabling the FETs. The HO output pin is used to control the high side FET and the LO likewise controls the low side. Since the HO and LO signals are 180° out-of-phase, it can be seen that when the high side FET is on the low side is off and vice versa. Therefore, a single IR2110 and two FETs can produce the proper switching necessary to operate one phase of the ac induction motor.

RESULTS

The prototype motor controller of Fig.1 has sucessfully been built to operate a 24 volt/24 amp three-phase ac induction motor. It is currently being tested to determine its efficiency. Once this testing is completed, the results will be compared to the efficiency of the motor using a 24 volt three-phase ac input to operate the motor. One possible conclusion that may come from these efficiency test comparisons is that using a square wave as the input to the motor severely restricts the performance of the motor. If this indeed does prove to be true, then the motor controller will have to be redesigned so that it produces a sine wave for input to the motor. This will be one of the first areas under investigation after completion of the efficiency tests.

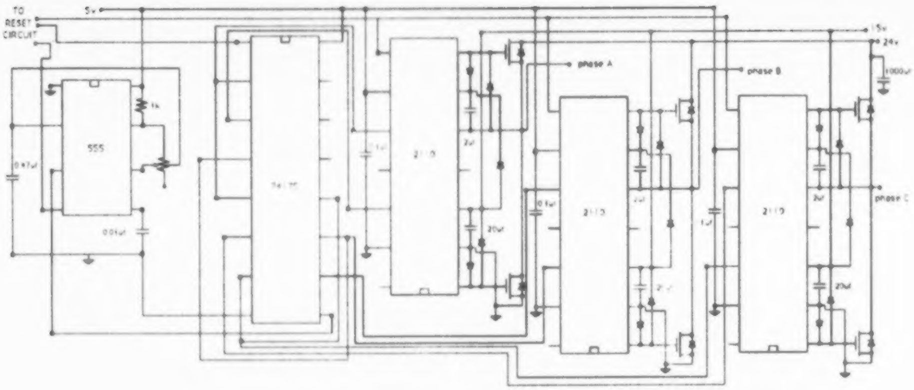


Figure 1 . The Prototype Inverter Circuit

CONCLUSIONS

The circuit reported in this paper, together with a specially wound 24Y ac induction motor have been used to show that it is possible to control the speed of an induction motor by means of a simple, low component, reliable inverter circuit. The low cost and extremely high life of the induction motor, plus its good characteristics for vehicle propulsion, make it an attractive alternative to permanent magnet dc motors.

ACKNOWLEDGEMENTS

The research leading to this paper was made possible by the support of the Potomac Edison Company, Virginia Power and NIDRR Grant H133E80003-90.

REFERENCES

[1] R.M. Inigo and C.W. Park, "Motor Analysis and Design," *Wheelchair Mobility 1989* , University of Virginia Rehabilitation Engineering Center.

[2] Leander W. Matsch and J. Derald Morgan, *Electromagnetic and Electromechanical Machines* , Harper and Row Publishers, 1986.

[3] John Voelcker and Glenn Zorpette, "Fast Electric Car Makes an Impact," *The Institute* , March 1990, p.6.

[4] "HV Floating MOS-Gate Driver IC," Application Notes AN-978A, *International Rectifier*.

R.M.Inigo
UVA Rehab. Engr. Center
P.O.Box 3368, U.Station
Charlottesville,VA 22903

10.8

THE DEVELOPMENT OF AN HMRC HEAVY DUTY JOYSTICK

Jerzy Antczak, Ihsan Al-Temen, Lynne Balfour & Stephen Naumann
Hugh MacMillan Rehabilitation Centre
Toronto, Ontario, Canada

ABSTRACT

A Heavy Duty Proportional Joystick has been developed primarily for powered mobility control. It addresses the needs of people who desire a proportional control system but whose spastic or athetoid movements preclude their use of standard joysticks. A previous design of a heavy duty proportional joystick has been demonstrated to be functional with clients, however mechanical difficulties have reduced its effectiveness. A new heavy duty joystick has been designed that addresses the technical difficulties. This design is presented here.

INTRODUCTION

The most frequently encountered commercial interface for powered mobility systems is the proportional joystick. It provides responsive and direct control of speed and direction. Some individuals however are unable to take advantage of this fine control because they do not have sufficient motoric control. Gated, micro-switch joysticks are an alternative that still provide direct control, but fine movement control of direction is lost. Less direct solutions such as scanning systems (1, 2) or touch sensitive interfaces (3) are yet another solution but again do not allow for fine control. While these alternatives provide solutions for individuals with more or less severe motoric impairments, there is a group of people whose needs are not addressed. These persons may have the ability to use proportional control but uncontrolled spastic or athetoid movements damage standard joysticks within a short time. Our solution was to employ a heavy duty joystick. Previously we had developed a heavy duty joystick utilizing a Penny & Giles JCP3 joystick assembly (4). To-date 11 of these joysticks have been provided to clients. Unfortunately various mechanical problems exist with this particular joystick. Therefore we have prototyped a new heavy duty joystick based upon our own mechanical and electronic design.

HARDWARE DESIGN CRITERIA

The principal design requirements for the development of the heavy duty joystick were as follows:

1. The joystick should be self centering and have strength and durability to be able to withstand the excessive forces applied by very strong, spastic users.
2. Total stick travel should be 14 degrees in any direction from the central position.
3. The overall package must be easily mounted on any type of powered wheelchair.
4. The knob mount should be modifiable to allow for mounting of different knobs and handle bars.
5. The device must be able to replace a number of commercial joysticks with differing electrical characteristics and ranges of movement.
6. The joystick must be able to be directly plugged into an existing interface input on the main power controller of the wheelchair.

DEVICE DESCRIPTION

Electronic circuitry has been designed to provide output signals that emulate a range of standard wheelchair joysticks. Since there are significant differences in these signals between various manufacturers, two separate electronic boards have been designed. One provides the differential voltages needed by Everest & Jennings wheelchair controllers while the other is compatible with the single ended inputs of the Invacare Arrow and Fortress Scientific wheelchairs. The positioning of ON/OFF and HI/LOW switches may be easily customized for each client to allow for accessibility and protection of the switches from the environment. Two light emitting diodes (LEDs) indicating HI/LOW speed and

ON/OFF status were mounted on a face plate of the joystick. The HI/LOW and ON/OFF switches were also mounted on the same plate close to corresponding indicators.

A commercially available 3/8" bore spherical bearing was selected as the basis for the design. The joystick has a 7/16" diameter stainless steel shaft whose diameter was stepped down to fit the spherical bearing, and captivated to the bearing with the retaining ring. This assembly is nested in a square aluminum block via a large internal retaining ring. The top end of the shaft was threaded to allow various lengths of shafts to be used. The opposite end of the shaft was reduced to 3/16" diameter to allow it to engage with two cradle assemblies that are at 90 degrees to each other. The cradle assembly was fabricated from two brass rotors connected to each other using two 3/32" diameter stainless steel rods placed symmetrically about the centre line of the rotors and spaced apart to fit the 3/16" diameter end of the stick. One brass rotor of each cradle assembly was directly coupled to a potentiometer. The cradle assembly was supported by two ball bearings housed in the main square aluminum block. This subassembly was fastened to the aluminum coverplate using four screws. A Delrin disc was fastened to top of the coverplate with a conical hole in the centre to serve as a mechanical stop and to limit the travel to +/-14 degrees. This arrangement is to eliminate the transfer of loads to the delicate cradles and potentiometer elements. The whole mechanism was housed in a cast aluminum box together with the electronics. A rubber boot is used to seal the top of the stick. Mounting holes and brackets are used to mount the joystick to the wheelchair arm rest.

CONCLUSION

A heavy duty joystick has been developed, suitable for clients particularly with spastic or athetoid cerebral palsy, who exert extreme force in arm movements.

ACKNOWLEDGMENTS

We would like to acknowledge the Metropolitan Toronto Police Association for their support of the Interface Program and its work.

REFERENCES

1) J. Antczak, "A Scanning Interface for Powered Mobility and Communication". Proceedings of the Sixth Annual Conference on Rehabilitation Engineering, San Diego, California, June 12-18, 1983, pp. 229-232.

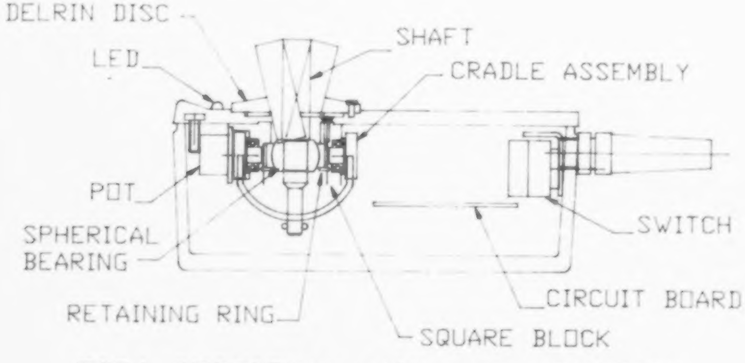


FIG.1 SECTIONAL VIEW OF JOYSTICK ASSEMBLY

2) B. Shire, "Microcomputer Based Scanning Interface for Powered Wheelchairs", Proceedings of the Tenth Annual Conference on Rehabilitation Technology", San Jose, California, June 19-23, 1987, pp. 541-543.

3) E. Snell, "Capacitive Touchplate Controller for Powered Mobility in Severe Motor Disability", Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, Washington, D.C., August 30-September 3, 1981, pp. 69-71.

4) B. Shire, "The Development of a Heavy Duty Joystick", Proceedings of the Tenth Annual Conference on Rehabilitation Technology, San Jose, California, June 19-23, 1987, pp. 683-684

Jerzy M. Antczak
Rehabilitation Engineering Dept.
Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario, CANADA, ,M4G 1R8

DYNAMIC COMPETITION SELECTION TECHNIQUE FOR COMPUTER ACCESS

T. Nantais, F. Shein, M. Milner and H. O'Beirne
The Hugh MacMillan Rehabilitation Centre
and the Institute of Biomedical Engineering,
University of Toronto,
Toronto, Ontario

ABSTRACT

A new selection technique for computer access is presented. This technique is based on a conceptual model of the experienced human listener in direct selection augmentative communication. It is hypothesized that redundancy in terms of the characters selected and in the pointing motions required to make selections can be exploited to reduce the amount of confirmation that the user must give during selection. Reduction in confirmation may reduce the physical burden of computer access for persons with severe motor impairments and result in increased efficiency of use.

BACKGROUND

Individuals who have difficulty using a computer keyboard because of motor impairments are often prescribed an alternate access system to replace the keyboard. The aim is to lessen the physical demands of entering characters while maintaining full functionality of the computer. One particular type of alternate access system continuously monitors the user's input (such as finger position); these have been labelled "auto-monitoring" access systems (Vanderheiden, 1973). Potentially, these systems offer an advantage compared to the standard keyboard since the keyboard is incapable of sensing or reacting to what the user's hand is doing until a key is pressed. The additional information associated with the continuous movement over a key has been used as a technique to select a key in the AutoCom (Vanderheiden, 1973).

If continuous motion of some part of the body is to be used to select from an array of possible items (e.g., letters), the user must have some means of indicating when a selection is to be entered into the computer. A "selection technique" is necessary because there is no longer a discrete switch associated with each possible selection as with a keyboard. Two selection techniques have been employed in previous auto-monitoring access systems. The first requires the user to activate an external switch when pointing within the area of the desired selection. The second relies on "relative cessation of movement" (Vanderheiden, 1988) inside some region around the desired selection. This second technique will be referred to as the static pause-time technique.

STATEMENT OF THE PROBLEM

Typical static pause-time strategies require that movement remain completely within a certain region for a specified time. This means that if the user momentarily leaves the region of that element, the selection process begins again from time zero, with no bias toward the element which had been receiving so much attention. Romich and Russell (1985) proposed an improved selection technique where there is a counter associated with each element in the selection set. Each counter keeps track of how many position samples have been found inside its corresponding region since the last selection. When any one of the counters reaches some specified value, that selection is made and all counters are reset. This softens the selection criterion to a competition between the candidate elements and has been shown to reduce the physical demands of access (Romich & Russell, 1985). This technique, however, does not take advantage of additional information available to the system which could be used to speed the selection process.

APPROACH

In this project, the possibility of extending the competition selection technique is explored for the purpose of further reducing the physical demands of access. In particular, the model of the experienced human listener in direct selection augmentative communication is used. It has been observed that the human listener speeds the communication process by echoing a prediction to the communication board user as soon as he or she is relatively certain which element the user intends to select. The selection criterion of the listener often exploits knowledge of redundancy in language and in the pointing motions themselves, resulting in correct interpretation even when pointing is unclear. It is proposed that an approximation to the listener's ability to exploit redundancy to bias selection towards certain elements over others will improve the efficiency of the selection process in a computer access system.

A technique similar to the competition selection technique is suggested where elements are chosen when pointing within the region of an element exceeds some minimum number of samples. However, we propose to vary the minimum number of samples or "activity quota" from element to element, with more probable elements being given lower quotas than less probable. This selection technique will be referred to as "dynamic competition." Both lexical probability distributions based upon previously entered selections and pattern analysis of the pointing motion itself are used to set the activity quotas. These are described below separately.

1. Lexical Probability Distribution

The characters that have already been entered can be used to evaluate each character's probability of being selected next (Shannon, 1951). A Markov Model is often used to store the probability distributions in the computer's memory. For our experiments, the Markov Model was built using a table of 5000 words and their relative frequencies. Knowledge of the frequency of the words was used to calculate the frequencies of characters within words given the characters that precede them. These preceding characters are called the context.

An example of the model's performance is shown in Figure 1. As shown, the number of characters used in the determination of the distribution (i.e., the context size) depends on how many characters in the current word have already been entered. It has been noted in previous work with lexical probability distributions (Foulds et al, 1987) that predictions made across word boundaries are a large source of prediction error in such a model. The model is not capable of producing a meaningful distribution for the first letter of a new word unless it is able to consider probabilities at the word level. However, the model is not so equipped. Therefore, all letters are considered equally probable for the first entry of a new word. The probability distribution for the second letter depends only on the first letter. Thus, the context used for producing probability distributions increases as more characters of a word are entered, up to a maximum size of four characters.

Once a probability distribution is calculated, the individual probabilities are converted into activity quotas through an arbitrarily chosen decreasing function such as an exponential decay. Parameters of this conversion function are chosen during the customizing process in order to fit the pointing qualities of the client.

2. Pointing Motion Pattern Analysis

The lexical probability distribution depends only on the previous entries and is set before the motion toward the next character begins. It is likely that the pointing motions themselves contain information about the motion's destination. Referring back to the experienced human listener model, it is not difficult to imagine a large part of the listener's "experience" consisting of the ability to use these motion cues to separate probable from improbable destinations on the communication board. Equipping the system with the potential to

Seq.	Context	Correct Next Entry	Prob.	Seq.	Context	Correct Next Entry	Prob.	Seq.	Context	Correct Next Entry	Prob.
1	-	T	0.037	8	SUN	S	0.14	15	I	S	0.10
2	T	H	0.33	9	SUNS	H	0.00	16	IS	b	0.63
3	TH	E	0.63	10	UNSH	I	0.037	17	-	W	0.037
4	THE	b	0.42	11	NSHI	N	0.20	18	W	A	0.20
5	-	S	0.037	12	SHIN	E	0.036	19	WA	R	0.017
6	S	U	0.019	13	HINE	b	0.78	20	WAR	M	0.057
7	SU	N	0.12	14	-	I	0.037	21	WARM	b	1.0

Figure 1: An example of the performance of the variable-context Markov model for determination of lexical probability distributions. The "context" is the string of previously entered characters used in the distribution's calculation. Only the probability of the correct next letter is shown here, but all probabilties are calculated by the model. "b" represents space.

infer the destination of a pointing motion from characteristics of the motion itself makes use of more information from the user and could result in reduced need for confirmation information like pausing.

To explore this hypothesis, a system was assembled for analysis of finger-pointing motions. Assume that the position of the user's finger relative to a letter board is known to the system. As the finger moves from region to region on the board, the task is to decide whether it will be stopping in its current region or moving to another, as illustrated in Figure 2 for a motion going from 'T' to 'H.' The arrows in the diagram represent points at which the system considers the destination question. The decision takes the form of a number, Gi, between zero and one with a low number indicating low likelihood that the region in question is the destination and a high number indicating high likelihood.

Neural Networks for Pattern Recognition

The details concerning selection of these numbers, Gi, are now described. A neural network model (Rumelhart et al, 1986) was chosen because of adaptability. A neural network is a collection of interconnected simple processors. Processing together, they can model complex signals from the outside world. The operation of the processors can be simulated on a microcomputer although electronically integrated neural network chips are becoming available which can process very quickly because they act in parallel. The real advantage of a neural network is that pattern classification problems are approached through observation of labelled training examples. No assumptions about the underlying process producing the patterns need be made. In this sense, a neural network learns by example as opposed to being programmed.

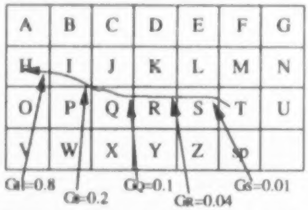


Figure 2: The pointing motion interpretation problem. See text for details.

It is possible for the selection technique to adapt itself to the particular pointing qualities observed over time from a particular user. Several neural-network-based pattern classifiers were examined and the arrangement shown in Figure 3 was eventually chosen. To accommodate differences in pointing ability in different areas of the board, *each* character on the selection board has a network with the structure shown associated with it. Each network is trained separately with pointing motions that have either stopped at or just crossed over its own region. Once trained, the task of each network is to determine the number "Gi" as soon as the finger crosses into its region.

Pattern Recognition Performance Evaluation

In a pilot study, the pointing motions were collected from a participant with spastic cerebral palsy who uses a direct selection letter board for face-to-face communication. Each pointing motion was examined separately and broken down into segments according to the regions that were crossed in the process of reaching the destination. If a region was simply crossed on the way to another, a desired Gi of 0 was associated with that motion segment. If a region was the target of a pointing motion, a desired Gi of 1 was associated with the motion segment that brought the finger into the target's region. The network gradually learns to imitate the desired outputs based on the motion segment information. The goal of this network training is to produce a reasonable output when presented with a new motion segment.

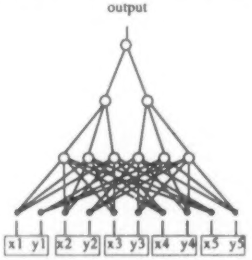
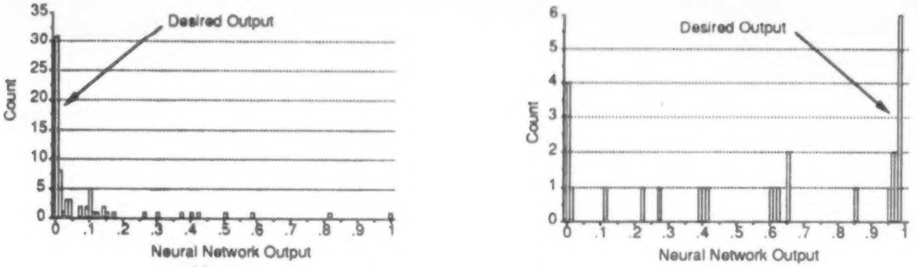


Figure 3: The neural network model used to predict selections. There is one network with this structure for every region containing a selection on the selection board.

After training, as a pointing motion passes over a region associated with a network, the single output unit of that network produces a number between zero and one indicating an estimate of the chance that the user's finger will stop in its region. If the networks are able to tell the difference between "stopping" and "moving on" early in the targeting phase of the motion, the activity quotas for candidate regions can be adjusted accordingly. In other words, a high certainty that the pointing motion will end in a particular region results in a reduction of the activity quota for the corresponding element so that it is easier to select.

Overall performance of all of the networks can be evaluated by comparing the desired output with the actual output for pointing motion segments that the networks had not previously encountered. Figure 4 contains two histograms showing the distribution of the network outputs for the two classes of desired output. Figure 4(a) is the frequency distribution of actual network outputs when the desired output was zero (i.e., "moving on"). Figure 4(b) is the same distribution for the motion segments when the finger was stopping in that region (i.e., desired output is one). Figure 4(a) contains many more entries than Figure 4(b) because there are many more instances where the region is only crossed over on the way to another target. There are 26 entries in Figure 4(b) because this is the number of times 'W' was the target in the trials.



(a)

(b)

Figure 4: Histograms showing performance of the neural network associated with the letter 'W.' (a) shows output when the letter region was crossed on the way to another letter. (b) shows output when 'W' was the destination.

Figure 4(a) suggests that the networks can tell when the pointing motion will not stop at their particular region with high accuracy. Figure 4(b) indicates a lesser degree of certainty when the pointing motion finishes in their regions. However, the large percentage of cases in Figure 4(b) where the output is greater than 0.5 demonstrates potential for significant savings in selection time through classification of pointing movements.

3. Prototype

The concepts described in the previous sections are implemented on an IBM PS/2 Model 30 286. The Markov Model uses 300 Kb of extended memory and the neural networks and the other control software are implemented in the 640K base memory of the computer. The position of the finger is sensed optically using a special-purpose video camera system and a passive marker mounted on the finger. Locations of the marker are fed from the camera to the PS/2 in two dimensions at a rate of 30 samples per second. A letter board is mounted on the table in the viewing area of the camera. As the user points to regions on the letter board, the camera relays the pointing information to the PS/2 which applies the dynamic competition selection scheme. In the current implementation, a commercially available keyboard emulator connects the PS/2 to a target PS/2.

This arrangement is currently being tested with the participant mentioned above. The experiment is a comparison between the prototype and the computer access system that this participant normally uses for writing. Results of the comparison will give an indication of the usefulness of the technique.

IMPLICATIONS AND DISCUSSION

The upcoming pilot study is meant to support the idea that a computer access system can relieve much of the physical burden of making selections by playing the role of a *familiar facilitator* like the experienced human listener in augmentative communication. Further clinical testing with the prototype is required to gain knowledge about the design criteria of such systems.

One likely result of clinical testing is the identification of the need for a more versatility in pattern recognition. Limitations of the current system are due entirely to computational considerations and not with the performance of neural networks. Neural networks are already appearing in fast hardware implementations and it is expected that computational considerations will not present a problem in the future.

Increasing generality of the pattern recognition section would improve adaptability of the system both to person-to-person variation and to variation in the selection qualities of an individual over time. Different pointing techniques such as headpointing, could also be accommodated with possible relief of problems such as neck fatigue through relaxation of selection criteria.

ACKNOWLEDGMENTS

Financial support from the Bloorview Children's Hospital Foundation (1990) and from an operating grant from the Natural Sciences and Engineering Research Council of Canada (1988-1989) for this project is gratefully acknowledged. Remote-sensing of hand position was made possible through the generosity of Sensor Adaptive Machines Inc. (SAMI) and technical support from Diffracto Ltd. Thanks are due particularly to Dr. T. Pryor and Mr. D. Fortin, both of SAMI, and Dr. O. Hageneirs and Mr. A. Gray of Diffracto. IBM Canada Ltd. is thanked for their donation of microcomputers on which this system was coded.

REFERENCES

Foulds, R., Soede, M., van Balkom, H. & Boves, L. (1987). Lexical prediction techniques applied to reduce motor requirements for augmentative communication. *Proceedings of RESNA 10th Annual Conference*, San Jose, pp. 115-117.

Romich, B. & Russell, N. (1985). An improved optical headpointer selection technique. *Proceedings of RESNA 8th Annual Conference*, Memphis, pp. 263-264.

Rumelhart, D.E., Hinton, G.E. & McClelland, J.L. (1986). A general framework for parallel distributed processing. In Rumelhart, D.E., McClelland, J.L. & the PDP Research Group, *Parallel Distributed Processing: Explorations in the Microstructure of Cognition, vol 1.* Cambridge, MA: Bradford Books.

Shannon, C.E. (1951). Prediction and entropy of printed English, *Bell System Technical Journal*, 30, pp. 50-64.

Vanderheiden, G.C. (1973). Auto-Monitoring Communication Devices for Handicapped Persons. United States Patent 3,854,131.

Vanderheiden, G.C. (1988). Overview of basic selection techniques for augmentative communication. In Berstein, L.E. (ed.) *The Vocally Impaired: Clinical Practice and Research.* Philadelphia: Grune & Stratton.

IBM PS/2 is a trademark of IBM Corporation.

ADDRESS

Tom Nantais
Microcomputer Applications Programme
Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario M4G 1R8
CANADA

11.2

WIVIK: A VISUAL KEYBOARD FOR WINDOWS 3.0

F. Shein, G. Hamann, N. Brownlow, J. Treviranus, M. Milner† and P. Parnes†
The Hugh MacMillan Medical Centre
†and the University of Toronto
Toronto, Ontario

ABSTRACT

WiViK™ is an acronym for Windows Visual Keyboard. It is a software application that displays an on-screen keyboard that enables users of Microsoft Windows 3.0™ to transparently enter text into applications through any pointing device that functions as a Microsoft Mouse.™ Equivalent keystrokes to a real keyboard are entered into the currently active application when a key is clicked with a pointing device within WiViK.

The WiViK keyboard is displayed within a moveable, resizeable window. It may be customized for: number and arrangement of keys, key widths, key labels, key label font, key spacing, and key colour. Keys are automatically resized when the keyboard is resized. Multiple WiViK keyboards may be displayed, each with a different key layout, and used simultaneously.

When a pointing device is used, all of the graphical user interface features of Windows are accessible, although some actions may still be difficult (Brownlow, Shein, Thomas, Milner, & Parnes, 1989; Treviranus, et al., 1990). Scanning is specifically not yet implemented because many problems are unresolved in supporting non-keyboard actions. This paper describes our developments to-date, proposed future developments, and unresolved issues.

BACKGROUND

Introduction

Many techniques have been developed to allow people with physical disabilities to use traditional text-based interfaces on computer systems. For example, people can enter text into a computer through alternative keyboards (e.g., expanded or miniature), by scanning and selecting from a keyboard displayed on a computer screen (visual keyboard) or separate device with as little as a single-switch, or by using Morse Code with one or two switches. Visual keyboards that provide transparent text entry have been available for several years on front-end computers (Lee, Shein, Parnes, & Milner, 1985), as pop-up windows in text-based interfaces (Dolman, 1987; Gorgens, Bergler, & Gorgens, 1990; Schwejda, & Vanderheiden, 1982), and as a separate application window on the Macintosh (Schoenberg, & Halleck, 1987).

Recently, Graphical User Interfaces (GUIs), such as Microsoft Windows 3.0 have gained widespread acceptance because of their ease of use. Unfortunately people with physical disabilities may find GUIs a tremendous barrier in accessing a computer. Most of the problems relate to the physical demands of the pointing device which involves: moving with relatively fine continuous control, clicking one or more buttons, dragging while holding the button, and moving between the keyboard and pointing device.

Solutions are starting to appear in the marketplace to address these problems. For example, Microsoft has recently released Windows 3.0 software developed at the Trace Center (Madison, WI) that will support 'sticky key' features and keyboard mouse emulation. Keyboard emulation through a serial link is also possible. The Trace Center has also developed a device that will provide these keyboard enhancements and emulation with any operating system on an IBM personal computer (Schauer, Novak, Lee, & Vanderheiden, 1990) including DOS,™ OS/2,™ and Windows 3.0. Current visual keyboards, however, will not function within Windows because it is a completely different operating system.

Statement of the Problem

Although keyboard modifications and serial linked keyboard emulations are available, the development of a visual keyboard within Windows 3.0 presents unique problems. These problems are seen in two areas: achieving functional text-entry; and supporting manipulation of GUI objects (windows, icons, menus, scroll bars, text blocks, etc.). Only the first area is of concern to users who have pointing ability. They can manipulate objects with some pointing device and only need support to enter text. Here, the point and click ease-of-use of GUIs is an advantage.

Users who have only limited pointing or clicking ability, or who may utilize an indirect scanning technique are at an extreme disadvantage. Manipulation of objects may be very difficult or impossible. It is suggested that a visual keyboard alone cannot solve this problem.

Rationale

After carrying out a two-year study of access to GUI environments, we have endeavoured to develop a series of visual keyboards that incorporate the positive features from existing ones and that begin to address the unique GUI access problems. This paper reports on the development of a new visual keyboard that supports users who have pointing ability. Typical users would be those with a high-level spinal cord injury. At this time, scanning was purposely not incorporated because adequate solutions for scanning within a GUI do not presently exist.

DESIGN AND DEVELOPMENT

We have separated visual keyboards into three separate classes:

- *Basic keyboard:* emulation of a standard IBM style keyboard, or part of a keyboard, i.e., the numeric keypad or function keys
- *Macro keyboard:* user-defined macro definitions of text and command functions
- *Predictive keyboard:* predictive display of a library of words and macro definitions

Rather than combine all of these distinct keyboard styles together in one visual keyboard, we decided to take advantage of the Windows environment and assign a separate window for each. This has several advantages including: individualized layout, sizing, and placement of each keyboard; reduced amount of information that needs to be displayed in a keyboard if not all styles are necessary or desired; and modular development. To-date, we have developed a basic keyboard, called WiViK, in several different layouts and international languages. A macro keyboard is currently under development and a predictive keyboard is planned for the future.

WiViK was programmed in Microsoft C and works with any IBM PS/2™ and MS-DOS compatible 286, 386, 486 microcomputer running Windows 3.0. A minimum of 2 Mb memory is suggested to run Windows effectively although WiViK itself only takes approximately 35K of memory. The standard keyboard remains functional throughout all operations.

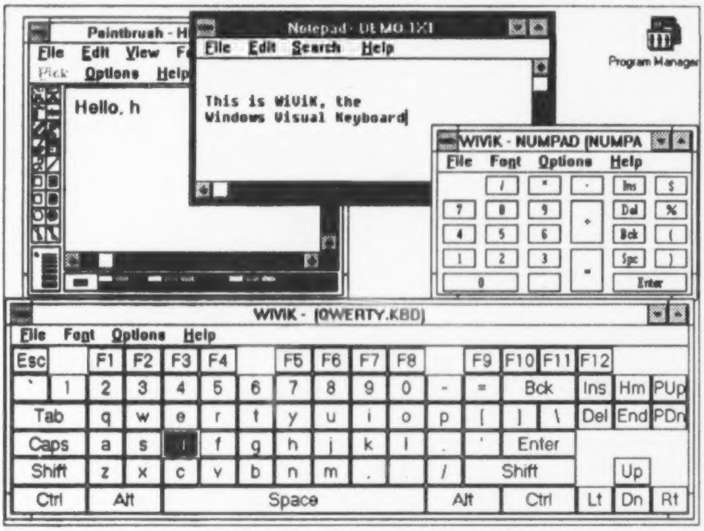
Any pointing device that emulates the Microsoft Mouse including mice, trackballs, touchscreens, and headpointing systems, will function with WiViK. The target application is first identified by clicking anywhere within its window. Keystrokes are then transparently entered into that application by pointing and clicking WiViK keys with the pointing device. Common one-finger 'sticky key' features such as latching shift, control and caps lock keys are built-in since there is always only one selection point.

The keyboard window may be positioned and sized using standard Windows operations. Access to all standard Windows functions by the pointing device is not affected by WiViK in any manner. Thus, both key entry and pointing control is available through a single device. The real keyboard remains functional at all times.

As an alternative to clicking, an option is provided that enables selections by dwelling over a key. Users may employ this to their advantage to quickly enter text without having to activate a switch for every selection. The pointing device's switch is still required, however, for actions outside of the visual keyboard. Users who are unable to operate a switch would be limited to text entry alone because of the nature of the Windows environment. This limitation is discussed below under "Unresolved GUI Access Issues."

Several layout and function options are provided, including:

- loading of pre-defined keyboard layouts and definitions from separate text files
- variable unit width and height keys
- automatic sizing of keys within the keyboard window when it is resized
- variable inter-key spacing: spacing between keys may be set to be none, small (10% of key size), medium (20%) or large (30%)
- a variety of screen fonts with automatic sizing of characters to fit within each key
- international keyboard characters
- multiple keyboard layouts which may be displayed and used simultaneously
- an option to lock the position of keyboard or allow the user to reposition it
- an option to lock the size of keyboard or allow the user to re-size it
- an option to always have the keyboard displayed above all other (including active) windows
- automatic storage of layout



This is WiViK, the
Windows Visual Keyboard

Figure 1: A standard layout WiViK plus a numeric keypad WiViK operating with two applications.

EVALUATION

Formal evaluations of WiViK have not yet taken place. In-house technical evaluations have been carried out to ensure that WiViK does indeed function as designed. Demonstration copies of WiViK have been distributed to several sites across Canada, the United States, Finland, Sweden, and England. In addition to evaluations by individuals with disabilities, WiViK is being examined by industrial companies because it is applicable to the general marketplace for such applications as point-of-sale systems and multi-media.

DISCUSSION

Access Features

Several design features enable WiViK to provide access to any Windows application. It is suggested that any implementation of a visual keyboard in a GUI should contain at least these features:

a) *Selecting keys in the visual keyboard should not transfer keyboard focus from the target application.*

While permitting multiple windows to occupy the screen, most GUIs restrict keyboard input, or focus, to one window at a time. Keyboard focus defines where keystrokes will be sent, and many GUIs only display selection highlighting and the insertion point in the window having keyboard focus.

Typically, keyboard focus is transferred to a window when the user makes a mouse selection within it. In WiViK, however, focus is only switched when it is moved, sized, or when its menu is used. Whenever the user clicks within its keyboard area, WiViK is programmed to send the key without obtaining focus. Thus, any highlights and the insertion cursor remain visible in the application and multiple visual keyboards may be operational at one time (Figure 1).

b) *The visual keyboard application should send keystroke information to the target application that currently has focus.*

WiViK achieves this capability by posting a sequence of messages to the Windows event queue. When the user clicks on a key, the appropriate virtual keycode is first determined. Then the destination of the keystroke is identified as the window with input focus (the target application). A 'key down' message is posted along with the virtual key code. Control to Windows is briefly yielded to allow the target application a chance to process the message. This is followed by a final posting of a 'key up' message along with the virtual keycode. The target application views these messages as if they were generated by the real keyboard.

A unique problem arises when sending keystrokes to select menu items with Alt-key combinations. The first Alt-key combination (e.g., Alt-F for file menu), pops up a menu as expected. Then, according to Windows convention, the user should point and click at a menu item or use a key equivalent to select an item. Clicking anywhere outside of the menu, by convention, closes the menu. Clicking a visual keyboard key to send a key equivalent would then normally close the menu without selecting an item. Therefore, an exception had to be programmed into WiViK to force the operating system to always consider a mouse click within the keyboard area as a key selection.

c) *The visual keyboard window should usually remain on top and be visible.*

In a GUI which allows multiple overlapping windows, windows rise to the top when selected for input. Any visual keyboard could then be obscured by another window. Although the user can always move windows out of the way with the pointing device, it can be a nuisance. On the other hand, if the visual keyboard is always forced on top of all other windows then a portion of an application may be obscured and it would be similarly bothersome to move the keyboard. WiViK's solution is to give the user the option to turn on or off its exclusive positioning above all other windows.

When the option is off, the visual keyboard rises to the top only when clicked; it may be temporarily obscured by any pop-up dialog boxes or new application windows. When the option is on, the visual keyboard will always be the top-most window. When the visual keyboard is 'minimized' or reduced to an icon on the screen the icon remains visible above all other windows.

d) *The visual keyboard should support a range of keyboard layouts.*

All key information used by the visual keyboard is stored in a text file that can be loaded into WiViK. This information includes key presentation characteristics (width, height, color), key arrangements, key label strings, virtual key codes, key types (normal, Shift, Alt, Caps Lock, Control). Layouts and key codes that differ among keyboard manufacturers and nations can be accommodated by entering their definitions into the text file.

A customizing program that will enable the user to change the keyboard layouts and key definitions is under development. When completed, the user will be able to use one visual keyboard to create another. However, it is anticipated that most of the customizing will be with the macro visual keyboard and that the basic keyboard will remain constant.

Unresolved GUI Access Issues

A number of problems exist in accessing all of the features that are common in a GUI such as Windows 3.0. A GUI employs gadgets such as menus, scroll bars, tool palettes and so on. Although a dwell time may be set to permit selection of keys by dwelling over a key, gadgets are inaccessible because only the visual keyboard itself is programmed to accept such action. Altering the software driver for the pointing device so that dwell time selections are accepted throughout the GUI is possible. However, this is only a partial solution because the targets for selection (gadgets and the insertion point) may be difficult to point at because of their various sizes compared to keys in the visual keyboard which can be sized to match the user's physical pointing ability.

Further, operation of gadgets goes beyond clicking and includes double-clicking and dragging. A simple dwell time is no longer a solution for these. Hamann (1990) has proposed an alternate solution for headpointing devices that includes both dwell times and gestures. A short dwell time selects a cursor position; a downward nod performs a single-click; an upward nod performs a double-click; shaking to the right clicks the right button; and continued dwelling initiates dragging which is completed by dwelling again. Dwell times and the gesture actions may be adjusted to individual preferences. Filtering may also be applied to smooth the movement of the cursor. Manipulation of small gadgets, however, still remains a problem if head control is poor.

The same problems exist if scanning is employed in the visual keyboard. Scanning to emulate the mouse is impractical for screen pointer and insertion cursor manipulation. The time that it takes to scan to a key repeatedly to move the cursor to select and move a block of text, pull down a menu or move icons is unacceptable. If a GUI is designed for total keyboard control then it may be possible to access gadgets and text by scanning to select the appropriate keystrokes but these may be different between applications. This would also greatly increase the number of items that must be scanned as well as increase the cognitive demands of the interface (remembering keystrokes) which is counter to the notion of a GUI reducing such loads.

Strategies must be developed that take advantage of the inherent feature of scanning which is the discrete selection of items. These must be applied to not only the visual keyboard but to the whole GUI environment. For example, the data itself, such as text, may be scanned within the application (Shein, et al., 1990). Perhaps the gadgets can be scanned directly. Intelligent agents may also be defined in the visual keyboard that can be delegated to perform tasks that typically involve movement. Another possible solution is to implement *virtual selection techniques* to accommodate users who cannot perform standard button selection actions. Selection could be mapped to a virtual code and movements could be mapped to a virtual technique. However, further research is required to identify and refine such tactics.

ACKNOWLEDGMENTS

We thank the University Research Incentive Fund of the Ontario Ministry of Colleges and Universities for their support. We also thank IBM Canada Ltd. and IBM Corporation for providing expertise and equipment.

REFERENCES

Brownlow, N. D., Shein, G. F., Thomas, D., Milner, M., & Parnes, P. (1989). Direct Manipulation: Problems with Pointing Devices. *Proceedings of the 12th Annual Conference of RESNA (Interdisciplinary Association for the Advancement of Rehabilitation and Assistive Technologies)*, New Orleans, LA, 246–247.

Dolman, L. (1987). Alternative access methods for the IBM family of personal computers and true compatibles. *Proceedings of the 10th Annual Conference of RESNA*, San Jose, CA, 687–679.

Gorgens, R., Bergler, P., & Gorgens, D. (1990). HandiWARE - Powerful, flexible software solutions for adapted access, augmentative communication, and low vision in the MS-DOS Environment. *Proceedings of the 13th Annual Conference of RESNA*, Washington, DC, 43-44.

Hamann, G. (1990). Two Switchless Selection Techniques using a Headpointing Device for Graphical User Interfaces. *Proceedings of the 13th Annual Conference of RESNA*, Washington, DC, 439–440.

Lee, K., Shein, F., Parnes, P., & Milner, M. (1985). The Elementary MOD Keyboard. *Proceedings of the Computer Technology for the Handicapped Conference*, Minneapolis, MN, 98–103.

Schauer, J., Novak, M., Lee, C., & Vanderheiden, G. (1990). Transparent Access Interface for Apple and IBM Computers: The T-Tam. *Proceedings of the 13th Annual Conference of RESNA*, Washington, DC, 255–256.

Schoenberg, A., & Halleck, J. (1987). Software for screen display of keyboard for no-hands typing via ultrasonically sensed head movements. *Proceedings of the 10th Annual Conference of RESNA*, San Jose, CA, 685–687.

Schwejda, P., & Vanderheiden, G. (1982). Adaptive Firmware Card for the Apple II. *Byte*, 7(9), 276-314.

Shein, G. F., Haataja, S., Brownlow, N. D., Treviranus, J., Milner, M., & Parnes, P. (1990). Direct Manipulation of Text by Scanning. *Proceedings of the 13th Annual Conference of RESNA*, Washington, DC, 147–148.

Treviranus, J., Shein, G. F., Thomas, D., Hamann, G., Milner, M., & Parnes, P. (1990). Modification of Direct Manipulation Pointing Devices. *Proceedings of the 13th Annual Conference of RESNA*, Washington, DC, 151–152.

IBM PS/2, DOS, and OS/2 are trademarks of IBM Corporation

Windows 3.0™, Microsoft Mouse, MS-DOS are trademarks of Microsoft Corporation.

ADDRESS

Fraser Shein
Microcomputer Applications Programme
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario M4G 1R8

Providing Computer Access Features under DOS

Mark Novak
Joseph Schauer
Jay D. Hinkens
Gregg C. Vanderheiden
Trace R&D Center
University of Wisconsin-Madison

Abstract

DOS is the most popular and widely used Operating System for IBM personal computers available today. Even though DOS has shortcomings and/or limitations, the population of DOS-based computer users continues to expand. While several Graphical User Interface (GUI) Operating Systems, such as OS/2™ and Windows 3.0™, are available for personal computers and were designed to avoid many of the DOS limitations, many disabled and non-disabled computer users, for various reasons, prefer to learn or remain operating under DOS. However, the inability of many disabled users to operate standard input devices, such as the keyboard and mouse, has many times prevented them from accessing a personal computer. Many third-party developers have created software patches which assist disabled and non-disabled individuals to access personal computers. These have not, however, addressed the full range of requirements set down by the General Services Administration (GSA). In particular, they have not addressed the access problems surrounding mouse-based software. A new software package of access features has been developed for DOS, which addresses all the GSA requirements for persons with physical (motor) disabilities. This access package includes access features for the keyboard and mouse and for alternative input devices. Currently under test, this access package for DOS is expected to be released in the spring of 1991. It is hoped that this access package can act as a "model" for direct incorporation of the access features into future versions of the standard DOS operating system.

Background and Statement of the Problem

The Disk Operating System is the most popular and widely used Operating System for IBM personal or IBM compatible computers available today. However, the inability of many disabled users to operate standard input devices such as the keyboard and mouse has prevented them from accessing personal computer systems. People with moderate physical disabilities may require assistance to access a computer due to one or more of the following reasons:

1) An individual may not be able to simultaneously depress more than a single key, preventing them from using most programs which require multiple simultaneous key depressions to perform tasks such as typing shifted characters, screen switching, menu activation, or cut and paste operation. Many times, this is the only major computer access barrier for people who type with a mouthstick, headpointer or have a spinal cord injury.

2) An individual may have poor coordination with slow or irregular response time or capability, which makes time dependent input unreliable. These individuals find themselves generating numerous unwanted key repetitions simply because they cannot release a key within the repeat tolerance of the keyboard.

3) An individual may have limited eye/finger (eye/stick) coordination and often strike unwanted keys before targeting the desired key. Those individuals who have hand tremors, eye/hand coordination difficulty, or utilize a headpointer or mouthstick often may spend more time trying to delete unwanted keys than selecting the desired key.

4) An individual without fine motor control, with paralysis, tremors, or using a mouthstick or headpointer for computer input, may not be able to control or manipulate a pointing device such as the mouse or joystick with fine enough movements or activate the buttons on a pointing device such as the mouse while simultaneously maneuvering the device.

Individuals with more severe physical disabilities often are unable to access a personal computer, even when modifications to the standard keyboard or mouse input devices are available:

5 These individuals require some mechanism to connect and use an alternate input device(s), to emulate the standard keyboard or mouse.

Approaches Taken and Implications

Many third-party developers have created software patches which assist disabled and non-disabled individuals to access personal computers. Perhaps the single most important and most often duplicated piece of "access" software performs the "sticky" key operation of the keyboard modifier keys (SHIFT, CONTROL, and ALTERNATE). These programs have various names, but all of them allow the one finger, mouthstick, or headpointer typist to type sequential keystroke combinations instead of pressing and holding multiple keystroke combinations simultaneously. This simple computer keyboard modification has provided computer access for many persons with disabilities. One common method to provide the "sticky" key action, was to use a DOS terminate-and-stay-resident (TSR) program. The TSR program would alter the codes sent to DOS from the keyboard for keys which were to remain "sticky" such as the SHIFT key, and after the "sticky" action was completed, the TSR program would provide the necessary house keeping to keep DOS in synchronization with the actual status of the keys on the keyboard. This method to perform the "sticky" action works well with those DOS applications which retrieve their keystroke information while using standard DOS keyboard function calls. This method does not work well with those DOS applications which read the keyboard hardware directly or hook the standard DOS keyboard function calls and replace them with their own calling methods.

Some of these same TSR software programs also provided for the adjustment of the key repeat rate and also adjustment of the length of time delay until a key starts to repeat.

The ability to adjust the amount of time a key must be depressed before it is recognized by the computer has not been as readily available as the DOS programs which provide the "sticky" key action. Many times, an individual with a disability who could benefit from a keyboard with a slower response, must resort to a mechanical keyguard over the keyboard or an alternate keyboard to prevent the depressing of unwanted keys.

The popularity of pointing devices such as mice as an alternate form of standard computer input has spurred the development of DOS application software requiring a pointing device for efficient operation. However, a DOS program which provides mouse emulation from the keyboard has not been available.

Several third-party manufacturers have designed and developed various alternative input or augmentative communication devices which can also be used to access a computer. Most of these devices consist of specialized hardware which can communicate with a computer through the serial or parallel port. Any software running on the DOS computer must be designed to receive the serial or parallel alternate device information and redirect it to the keyboard or mouse software handlers, typically called "drivers". This DOS computer software must also understand the alternate device communication protocol or "how to decode" the alternate device information into appropriate keyboard and mouse codes before it can send the information onto the keyboard or mouse drivers. Efforts initiated by the Trace Center and early alternate device manufacturers have led to the unofficial adoption of the Keyboard Emulating Interface (KEI) Standard. The KEI Standard outlines a common series of alternate device commands, to allow alternate input devices manufactured by different third-party companies to emulate the keyboard while communicating with a computer running DOS. The KEI Standard however, did not provide any commands to provide pointing device or mouse support, limiting users of alternate input devices to the ability to do keyboard emulation only.

In the early 1980s, the Trace Center developed a TSR program called "1-Finger" that runs on DOS based computers. 1-Finger provides the computer user with "sticky" key and adjustment of the key repeating. These keyboard enhancements are now commonly referred to as "StickeyKeys" and "RepeatKeys" respectively. Due to the popularity and demand for 1-Finger, the Trace Center has maintained and upgraded the program as new computer hardware and new versions of DOS were developed or released. While people with disabilities who required the "sticky" key action or required adjustment for key "repeating" have used 1-Finger with good success, other disabled users who require a slower keyboard response, an alternate form of pointing device control, or a method for their alternate input device to access the computer have not been helped by 1-Finger. Also, while 1-Finger requires only 1500 bytes of space when operating in its TSR state, it still is subject to TSR conflicts, and 1-Finger has difficulties with DOS applications which do not use DOS keyboard function calls to retrieve keystroke information.

Since there has been a high demand for additional functions from programs such as 1-Finger, and since the Family 2 IBM Personal System 2 (PS/2) computers allow direct insertion or injection of both keyboard and mouse information, the Trace Center decided to launch a new effort to totally upgrade the 1-Finger program. The new program will provide similar functionality for the IBM PC/XT/AT computer hardware as the current 1-Finger program. These include the "StickeyKeys and RepeatKeys" keyboard enhancements while remaining a DOS TSR program. For computers running DOS which contain the necessary hardware, the new program will also provide the "SlowKeys and MouseKeys" features. SlowKeys allows the computer operator an adjustable delay time before a depressed key is accepted by the computer, thus slowing the keyboard's response. MouseKeys allows the computer operator to control the pointing device or mouse, from the numeric keypad keys on the keyboard. For the IBM PS/2 Family 2 computer, the new program will take advantage of the new hardware insertion or injection capability to provide a greater degree of transparency for DOS and DOS applications since any injected keyboard and mouse information will seem to have originated at the standard keyboard or mouse.

The new program will also allow serial port access for alternative input devices, on computers with the hardware to support it. This form of access, utilizing the serial port, has been dubbed "SerialKeys", and will allow for both keyboard and pointing device emulation provided the alternative input device follows commands and protocol outlined in the General Input Device Emulating Interface (GIDEI) Standard. The GIDEI incorporates much of the original KEI Standard, but has also been expanded to include pointing devices.

The software programming for the new program is scheduled to be completed in February, 1991. A two-month in-house and third-party testing program is scheduled after software completion. Therefore, the new program is scheduled for release in the spring of 1991.

Discussion

This work is a natural extension of previous access work which will hopefully lead toward direct incorporation of the access features into the standard operating systems.

In September of 1990, the Trace Transparent Access Module (T-TAM) was released. The T-TAM is an external hardware device which attaches to the IBM or Macintosh computer through the standard keyboard and mouse port, and also provides the same features as reported in this work. The T-TAM has the further advantage of being external to the computer, making it both 100% transparent access and also operating system independent.

In October of 1990, Microsoft Corporation began distribution of an Access Utility Software Package for the

Windows 3.0™ operating system. The Access Utility Software Package for Windows 3.0™ was developed at the Trace Center. The Access Utility Software Package contains replacement keyboard and mouse drivers which are part of the Windows Operating System and provide the same features as reported in this work. This package was released by Microsoft as a standard item in their third-party drivers package for Windows 3.0™.

The work reported here extends the theme of "developing methods for these access ideas to become part of the standard". This new program which combines access features for the keyboard, mouse and alternate input devices (such as a communication aid) will provide a comprehensive computer access package for people with physical disabilities who want to access an IBM computer running DOS. It is hoped that the development of these extensions to the standard operating system systems will lead to the direct incorporation of these features in future releases of the operating systems.

Acknowledgements
This work has been supported in part by Grant #H133E80021 from National Institute on Disability and Rehabilitation Research, U.S. Department of Education.

The investigators of this work have also consulted with IBM on the requirements for IBM computers.

Mark Novak
S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

11.4

THE USE OF INTEGRATED CONTROLS FOR MOBILITY, COMMUNICATION AND COMPUTER ACCESS

Kevin M. Caves, Kathleen Gross, Kathy Henderson, Adrienne A. Minson
Rancho Rehab Engineering Program and Rancho Los Amigos Medical Center
Downey, California

ABSTRACT

Access to assistive technology by severely disabled individuals can be difficult. This paper describes the use of integrated controls to access powered mobility, communication and computer technology, by an individual with C1-C2 quadriplegia. He uses a pneumatic wheelchair control to access two switch Morse code on an IBM compatible computer, and a custom modified intra-oral electrolarynx for communication. After six months of intermittent training, he is communicating with the electrolarynx and typing over twenty words per minute. The evaluation, system setup and problems encountered are described.

BACKGROUND

Omar is a 20 year old male who had a C1-C2 spinal cord injury resulting in complete quadriplegia, in 1988. He has severely limited head range and is ventilator dependent. He also has nystagmus, a visual problem which makes it difficult for him to focus on text.

He was using a mouthstick to type on an electric typewriter when we were first consulted to look at assistive technology with him. Working approximately one hour a day typing letters to friends and family, Omar reported that it would take him approximately five hours to complete a page length letter.

Omar drives an Everest & Jennings Marathon power wheelchair with a Dufco pneumatic controller (sip and puff). The wheelchair controller allows the user to control devices which can be accessed using single switch closures. The wheelchair has a power recliner which is controlled through the Dufco system.

EVALUATION

Omar was evaluated by the assistive technology team for communication and computer access. The team consists of an occupational therapist, physical therapist, speech pathologist, and rehabilitation engineer.

Omar has normal cognition and is quick to grasp concepts. He received his high school diploma while an inpatient. During the initial interview, he stated that he was not interested in a communication device which would speak for him, but he may be interested in using a computer to write his letters.

The evaluation showed that the he has severely limited head range but can reach most of the keys on a typewriter keyboard using a mouthstick. Due to a collapsed trachea he cannot phonate, making speech production impossible.

COMPUTER ACCESS

Due to the severity of his physical limitations, Omar and the technology team looked at switch access as a substitute to the mouthstick. Scanning arrays proved difficult due to his visual problem and he had difficulty using a number of switches. Omar and the team decided on an IBM compatible system with two switch Morse code entry to the WordPerfect wordprocessor. Based on the difficulty he had with the evaluation switches, the system was setup so that Omar could access the computer through his pneumatic controller. Morse Code WSKE from Words Plus of Sunnyvale, CA, was used as the access program. WSKE was chosen because of its rate enhancement options, and known compatibility with standard wordprocessing software.

The equipment was initially configured taking advantage of the rate enhancement features of the Morse code software, word prediction, abbreviation expansion, auto-capitalization and auto-punctuation. These options can reduce the number of keystrokes needed during text entry and can increase typing speed.

Training was intermittent, generally three hours per week, due to his medical instability. After one month Omar had learned the Morse alphabet and was typing at a rate of approximately five words per minute. He was not using the word prediction feature of the program because "it slowed [him] down." Omar reported that he could type a word faster than he could locate and select it from the prediction list. Consequently, the word prediction option was removed from the configuration.

After the second month of using the computer system, his speed had not increased much. It appeared that Omar was typing faster, but the typing errors sometimes caused the abbreviation expansion to produce phrases, which then needed to be corrected. The abbreviation expansion and the auto-punctuation/capitalization were removed from the configuration and his mistakes decreased greatly, pushing his input speed up over twelve words per minute.

By the end of the third month, Omar was typing approximately eighteen words per minute. He could type a letter in about an hour.

Omar recently expressed an interest in exploring other options with the computer. We are currently in the process of installing the necessary phone lines to connect with the Prodigy service. Due to the high memory requirements of the graphics based service (almost 500K), the WSKE program would not fit in memory with Prodigy. What was needed was a Morse code access program which requires less than 80K of memory.

HandiCode from Micro Systems International, requires approximately 60K of memory, works with Prodigy. The codes for the alphabet and numbers are the same between the two programs, because these are standard Morse code. The special keys and characters needed to operate a computer, (for example the function keys, control key, alternate key, cursor control key, asterisk) need to be coded also, and each company has done this differently.

We are investigating the possibility of using a remote link from the wheelchair to the computer so that Omar could independently use a computer.

COMMUNICATION

At first not interested in communication technology, his positive experience with computer technology has changed his opinion towards a communication device. Since then we have provide him with a small custom communication device.

An intra-oral electrolarynx is a device commonly used by individuals who have had a laryngectomy. The device has a tube which the user places in his mouth which delivers the sound directly to the oral cavity. This device was integrated into the wheelchair system.

The integration of the communication device has two parts: physical and electrical. The device was physically integrated by purchasing a tubing "T" union and splicing the into the breath tube.

The electrical integration required a switch that Omar could operate. Again, the pneumatic controller of the wheelchair was used, but a latched switch was required, and the Dufco system could only provide a momentary switch closure.

A small electronic switch latching box was constructed and placed between the device and the wheelchair controller, which upon receiving a momentary switch closure from the wheelchair, latches the device on. A second momentary switch closure turns the device off.

DISCUSSION

Advancements in power wheelchair control technology have made possible the integration of mobility, communication and computer access. For individuals who have limited access sites, this integration has many advantages.

Morse code is a fast, efficient, direct selection technique, which is very good for text entry to a computer. It is especially useful for severely physically involved individuals, because it can be operated using one or two switches. In the case of an individual who controls a power wheelchair by sip and puff, Morse code is especially desirable. Additionally, since the access technique does not require visual scanning, it is an input possibility for people with visual impairments. The use of this technique requires learning Morse technique, and may not as effective for non-text applications.

ACKNOWLEDGEMENT

This work funded in part by the Las Floristas/Kenneth & Harlyne Norris Center for Applied Rehabilitation Technology.

Kevin M. Caves, B.S.
Rancho Rehab Engineering Program
7503 Bonita Street - Bonita Hall
Downey, CA 90242

11.5

AN ALTERNATIVE APPROACH TO COMPUTER ACCESS: THE "ADAM" INTERFACE FOR THE MACINTOSH™

Randy J. Marsden, B.Sc. EE.
Greg J. McGillis, B.Sc. EE.
Madenta Communications Inc. (Edmonton, Canada)

ABSTRACT

The Apple desktop bus Data Acquisition Module, or ADAM, is a hardware device aimed at providing "raw" input data to the Apple Macintosh™ for the purpose of creating a more flexible computer access scheme for people with disabilities. A premise is made that existing methods such as keyboards which directly map an input action to a computer function are too limiting for people who are unable to access them effectively. This paper describes the development of a system which strips away this layer of definition by providing the computer with more rudimentary input information which can then be customized to computer functions in a way that is more suitable to the disabled user.

BACKGROUND

Since the invention of the modern typewriter in 1867, relatively minor improvements have been made to the way humans input information into machines. The keyboard remains the primary means for data input , a job it seems to accomplish adequately for the able-bodied masses. Since the advent of computer technology, other input devices such as the mouse and graphic tablets have been implemented. These devices complement the keyboard, but with rare exceptions, aren't a suitable replacement for it.

STATEMENT OF PROBLEM

The problem is two-fold. First, existing keyboards are at best inefficient if not impossible to use for a person with certain physical disabilities. This much is obvious. The second problem is less obvious however. Most solutions to this inaccessibility are adaptations or emulations of the keyboard - the very device considered inappropriate.

The statement of the second problem suggests that an alternative input scheme must be devised. This however offers a third and final problem. Most personal computers don't provide a *direct* way of inputting more rudimentary data that doesn't necessarily follow the metaphor of a keyboard. Such a scheme would require a hardware adaptation (like the Adaptive Firmware Card).

RATIONALE

When the first keyboard was developed, its inventors immediately mapped raw input actions to a specific function; pushing a key resulted in a letter being typed. Today, with an ever broadening range of computer applications, it would seem limiting to continue with this idea of direct mapping. Trying to force a person with disabilities to adapt to the standard keyboard metaphor is much like trying to talk an Eskimo into living in a Pygmy hut - it simply isn't appropriate since their needs and resources are different.

We resolved to take a fresh look at exactly how humans interact with machines, and to try and strip away that extra layer of definition which was provided 120 years ago by the inventors of the first typewriter. By so doing we hoped to find a better type of interface for people who are physically challenged.

Before we could develop software that could accomplish this, we needed a way to get the information into the computer in its rawest form. This meant not developing another keyboard or mouse, but rather a device that collects data and promptly lets the computer know all the possible attributes of it (such as when it occurred and where it came from). We are handing the computer a lump of clay from which it can sculpt what is appropriate for the user, rather than a pre-formed vase that can only be painted a different color.

DESIGN

The objective of our design is to provide a system which gathers and sends data to a personal computer without any pre-defined function attached. An example of what the computer then does with this information is briefly outlined in the inset article to give the reader a general feel for possible applications.

The ADAM was intended from the outset to be a commercial product, and therefore was subject to a few limitations. Firstly, we were constrained to support only existing, commercially available input devices. Second, we had to base the design on existing microcomputer products. In short, the design was constrained to not just existing technology, but to technology readily available to the potential user. Below, we describe the choices for this technology, and how we implemented them in our design.

Choice of Computing Platform

A common theme in our design is to leverage off of existing technology that we likely couldn't significantly improve on if we did it ourselves. This remains true in our choice of a computing platform. Rather than build a stand-alone unit from scratch, it was deemed more important to use an existing technology with readily available third party hardware and software. As developers, this allows us to concentrate on computer access and not word processors, for example.

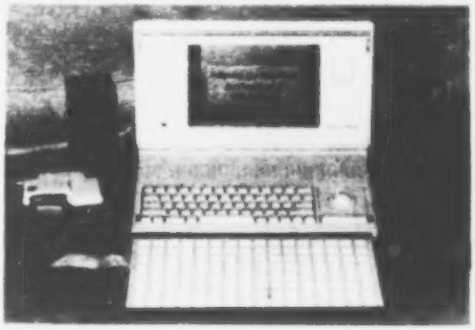


Figure 1. ADAM Unit (left) in typical configuration

In today's market the above criteria are met best by two obvious platforms: DOS and Apple Macintosh™. Although recent products have significantly improved the graphical user interface (GUI) of DOS machines, we chose the Macintosh for our initial design because of its proven interface, ease of use, and the structure of its operating system software.

Choice of Switches

After choosing the Macintosh for our platform, the next task was to identify the specialized input devices that we should support. To help us identify these devices, we considered data from our own surveys given to potential users, care givers, and professionals; government statistics; catalogue and market information from commercial suppliers; standards established by the Trace R&D Center; and other related technical articles (1). The results of our findings, displayed in Table 1 , indicate approximately one third of all disabled persons are single switch users, with another third using either regular or expanded keyboards.

Given these findings, we chose to support single/dual switch input via three 3.5mm stereo mini-jacks, and expanded keyboards via a 36-pin centronics connector. This configuration supports SET standard inputs either directly, or via an adaptor.

As can be seen, all of the switches we have chosen to support are digital (ON/OFF) input devices. This is because there are relatively few analog devices commercially used. However, we feel valuable information is lost when only simple digital input it used, and plan to support analog devices in the future as that technology develops. For example, input could be received from proportional sip-puff devices, from analog levels representing muscle expansion or contraction, or voltages that represent the signals that are transmitted along nerve fibers.

Industrial Design

In designing the enclosure we felt it necessary to accomplish two things: a) create a design that is coherent with other Macintosh products, and b) an attractive design that is non-institutional looking, functional, and appealing to the user. We put forth considerable effort using an industrial designer and getting feedback from care givers and users. The result is an enclosure that has the image of compactness, portability, functionality and consistency with other Macintosh products. (The ADAM is shown in Figure 1, to the left of the computer).

Data Representation

The manner in which data is collected and presented to the Macintosh is at the heart of the design. A single ADAM unit can accept input from up to 134 possible switches. (Note: a "switch" may not only be a regular switch, but perhaps a voice command, eye movement, or any other type of input physically possible) The ADAM puts a "time stamp" on each transition (high to low or low to high) of any switch.

This time stamp is the moment in time to the nearest 1/20th of a second (50ms) when the switch was asserted or de-asserted. It communicates this information to the Macintosh via the ADB protocol, calling our own ADB Driver (see Figure 2). This software is passed a switch number, a device number (since more than one ADAM can be connected at a time), and a time stamp. The driver then stores this information in a table in the Macintosh which contains a record of the last ten transitions of that same switch. This historical record is then available for further processing (see inset article).

It can be seen that the information communicated to the computer

Mapping Input to Functionality: "Triggers"

To demonstrate the advantage of supplying input data in a raw format, an example of what we have done in software is briefly presented here. Figure 2 shows the ADB driver supplying input information in table form. This table contains a historical record of the past ten transitions of any given switch. Software, which we have called the trigger driver, then interprets the table and maps it to specific functions (or output triggers) as defined by the user. For example, the function "save" may be invoked by "switch 9 held for 1 second followed by switch 3 for any length of time"; or the function "escape" may be invoked by "switch 1 actuated 3 times within 2 seconds". The permutations are infinite.

Output triggers may also be fed back to create subsequent output triggers. For example, "Quit if Save is true, *and* switch 7 is actuated". ("Save", which is an output trigger, participates in creating "Quit", which is also an output trigger). Output triggers are used by the active application and system via an "Inter-Application Communication" (IAC) link.

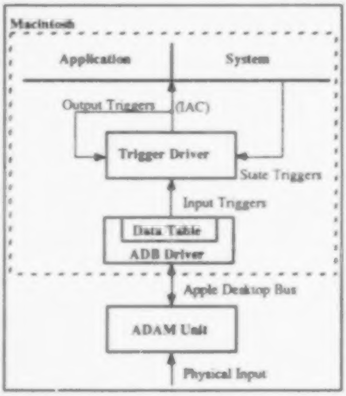


Figure 2: How information is disseminated

The third input to the trigger driver is called a "State trigger". These triggers are supplied as input to the trigger driver from system level software. State triggers tell the trigger driver the current context of the computer, or in other words, what the computer is doing right now. Typical state trigger examples may be: currently over a close box, currently in a dialogue box with OK and Cancel options, and currently over the menu bar. This means that the trigger driver can create different output triggers from the same sequence of inputs, providing different state triggers are used.

For example, a double-click on switch 1 may be mapped to a mouse double-click function at all times except when an "OK/Cancel" dialogue box is presented, at which time it may mean "Select Cancel" (since a double-click in such an instance wouldn't make sense). This shows how intelligence is added to a single switch, enabling it to control the entire interface.

In fact, we are supplying three dimensions to a single switch where there used to be only one. The first, of course, is whether the switch is open or closed. The second dimension, incorporated by Samuel Morse in 1837, is the element of time. The third is the idea of taking the current context of the computer into account, and changing the meaning of the switch accordingly.

The danger with such flexibility will be the development of user interfaces and triggers that are too complex and confusing for the typical user. Research is presently being conducted into optimal use of the trigger concept to avoid this eventuality. This research however, is beyond the scope of this paper.

BEST COPY AVAILABLE

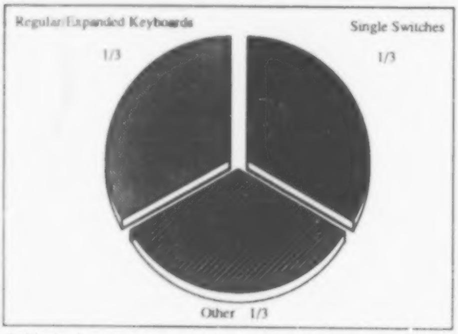


Table 1: Input devices used by people with disabilities

has no specific function attached to it. It is simply a table containing raw information about past and present states of inputs. By supplying the computer with information in this format, we have accomplished our original design objective.

DEVELOPMENT

Communication between the ADAM unit and the computer is done via the Apple Desktop Bus (ADB). The ADB bus is a serial bus intended for human input devices. The usual devices that connect to this bus are either the mouse or the keyboard. Up to 16 devices, including the ADAM can be daisy chained on the ADB. Therefore, the ADAM can be on the same bus as another ADAM module, keyboard, mouse, graphics tablet, headmaster, or other specialized device, and not interfere with the operation of any of them. This is an important feature in this market where many different input devices exist (2).

In order to operate as an ADB device, the ADAM was assigned a unique ID and address from Apple. This means that the ADAM is not a mouse or a keyboard, but is a unique, separate device.

Not only did we need to license our ADB device with Apple, but FCC approval was also required to operate a commercial electronic device. This meant passing the FCC Part 15 Class B rating. To do so required a modification of the circuit board layout and the inclusion of specialized filters and shielding materials. This fulfills the requirements of law, and prevents the ADAM from interfering with surrounding electronic devices.

EVALUATION

The task of evaluating the ADAM is to determine if it does what we intended it to do; if the presentation of raw data to the software increases the user's control and rate of control. This requires not only extensive testing and feedback from users, but will first require expanding their understanding of how a human can input to a computer. This means replacing the traditional keyboard emulation idea with the trigger concept discussed in this paper. This will require some time because of the difficulty in adjusting to new ideas.

However, the initial performance and consumer response has been favorable. We received a great deal of positive feedback when we demonstrated the ADAM, along with complementing software, at the Closing the Gap conference in October 1990. The choice of supported input devices met with approval, and the ergonomics and esthetics were found to be appealing.

Also important in an evaluation of the ADAM is a comparison of its operating principles with other devices such as the Trace Transparent Access Module (T-TAM). The basic idea behind the T-TAM is that it functions as a Keyboard and Mouse Emulating Interface (3). This means that all inputs are intercepted and converted to emulate either a keyboard or a mouse. The advantage of this scheme is that it is transparent to the system and application software on the computer and therefore always compatible.

While this is valuable for input devices based on the keyboard metaphor, as already stated the ADAM represents an alternative to this metaphor. Our design does require software on the host computer, but it is our belief that system incompatibilities can be avoided by careful design and implementation.

The concept of low-level input has proven useful in other applications as well. An example of this is a medical experiment where the patients activate a switch while their brain activity is monitored. Since the switch actuation is time stamped inside the ADAM, the clinician is able to correlate the brain activity to the exact time the patient activates the switch.

Extensive testing by users has not yet taken place. At the time this paper was written, 10 Alpha units were being manufactured. They will be placed at various test sites with people of varying disabilities. This will give us valuable feedback that will shape how the software works, but will probably not significantly change the hardware design of the ADAM.

DISCUSSION

The ADAM successfully gathers raw input data, time stamps it, and passes it on to the Macintosh via the Apple Desktop Bus. It is clear that this scheme is only the necessary front-end for a more powerful software system that will allow the user to delegate what they want the computer to do, rather than be manipulated by adaptations to conventional input devices (4).

The ADAM is a tool which, if used correctly, will form the basis for a computer access system supplying a degree of adaptation and flexibility beyond that which is presently available. By so doing, it will provide disabled users with increased freedom of communication, improved productivity, and enhanced quality of life.

REFERENCES

1. Schauer, J., Rodgers, B., Vanderheiden, G., Kelso, D., Simple Electrical Transducer (SET) Standard, Version 1.0, p. 1-22, Trace Research and Development Center, Madison, WI, 1988.

2. Hershberger, D., Connecting Peripherals to AAC Systems through a Common Communication Bus. Proceedings of the 13th Annual Conference, p.95-96, RESNA, Washington, D.C., 1990.

3. Schauer, J., Novak, M., Lee, C., Vanderheiden, G., Kelso, D., Transparent Access Interface for Apple and IBM Computers: The T-TAM. Proceedings of the 13th Annual Conference, p. 255-256, RESNA, Washington, D.C., 1990.

4. Brownlow, N., Shein, F., Treviranus, J., Milner, M., Parnes, P., Don't Manipulate, Delegate! Proceedings of the 13th Annual Conference, p. 153-154, RESNA, Washington, D.C., 1990.

Randy Marsden, B.Sc. EE.
Madenta Communications Inc.
#216 Advanced Technology Center
9650 20 Ave., Edmonton,
Alberta, Canada T6N 1G1
(403) 450-8926

ALTERNATIVE WRITING DEVICES FOR THE INEFFICIENT WRITER

Aimee J. Luebben and Robyn B. Oeth
Community Services
Belleville, Illinois

ABSTRACT

Even with educational technology, there is a strong visual motor component in the average public school classroom. Students who cannot cope with the visual motor aspect are often classified as having learning disabilities when they are simply have "school" disabilities because they are inefficient writers. This paper presents the decision making process including criteria for judgment for an alternative writing system for a student who has difficulty with the fine motor component of the standard writing process.

BACKGROUND

There is a renewed emphasis on teaching with regard to various styles of learning and an increased incidence of students being referred for evaluation for suspected learning disabilities. For various reasons some students have difficulty in school related tasks and may never become proficient in pencil and paper tasks, particularly in those activities that have a time limit. Difficulties may lie in one or a combination of different factors including grasping standard writing implements such as pens and pencils, planning the complex motor activity of writing, and performing the visual motor act of copying from the board.

With technology every person has the chance to increase productivity; this includes the student who has a disability associated with school related tasks. Communication devices, particularly voice output communication systems, have received attention and outside funding on a more regular basis. One area that is just beginning to be explored is written communication. Mandated by P.L. 94-142 and Section 504 of the Rehabilitation Act, schools must provide students with the technology needed to be mainstreamed with regular students.

OBJECTIVE

With the advent of more notebook sized computers coupled with the falling prices of computers in general and decreasing size and weight of battery powered computers, it is now feasible for those students who have difficuly with the fine motor aspect of writing to utilize an alternative writing system. The objective was to locate notebook style computers that weighed under five pounds and cost less than $600.00 and determine the optimal match with a third grade student with learning disabilities.

METHOD/APPROACH

After experiencing more difficulties in the third grade even with the services of a resource teacher for students with learning disabilities, S., a nine year, six month old girl, was referred for a occupational therapy assessment to evaluate functional performance. Since many school related tasks students are required to perform have visual motor elements, standardized testing for visual processing, visual motor, and fine motor abilities was conducted. S. scored at the 14th percentile on the Test of Visual Motor Skills, an assessment of the motor act of copying designs; at the 92 percentile on the Test of Visual Perceptual Skills, a nonmotor visual processing assessment; and at the 14th percentile in the fine motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency, an assessment that examines initiation of response, school tool utilization, and manipulation skills. When separating S.'s below average visual motor skill performance into the visual processing and fine motor components, it is evident that S. was strong in visual processing skills, but her primary difficulty was in the fine motor area. Clinical observations included inadequate trunk stabilization, difficulty controlling school implements related to her method of grasp and stabilization, and slow motor planning. When asked to copy the first two words with three inch letters from a poster six feet away, S. made four errors out of a total of 12 characters. When given a notebook computer, S. copied both words without errors. While there is a MS/PC DOS computer system in the office for administrative tasks, the Apple II series of computers comprise the computers in the classrooms. Both serial and parallel printers are in various locations throughout the school.

RESULTS

After meeting with school personnel and family members, the district decided to provide a notebook style computer for S.. Two factors further influenced the selection of the notebook computers: weight and price. It was determined that the notebook computer should weigh no more than one-tenth of S.'s weight of 50 pounds, so the top limit for a computer was set at five pounds. The ceiling price level for device purchase was set by the district: after some discussion, the school district allocated $600.00 for the purchase. Four notebook computers met the dual criteria of weight and price: the Tandy 102, the WP-2, PC-3, and the Portfolio.

The Tandy 102 is available from most Radio Shack or Tandy stores for $599.00. Weighing three pounds, this machine has a length of 8.5 inches, width of 12 inches, and a depth of 1.3 inches. The Tandy 102 has a flat LCD screen that displays 40 characters by eight lines; the background can be adjusted for better viewing in various lighting. This device has a standard sized keyboard and interface ports for parallel, serial, cassette, and bar code devices as well as a builtin 300 baud modem. The ROM resident Microsoft software includes BASIC, a telecommunications package, a scheduling and address file, and a rudimentary word processor. Files developed in the BASIC or word processing mode may be saved in battery backed RAM; 32K is included in the price and memory upgrades may be purchased by third party sources.

The WP-2, another product from Radio Shack, is a dedicated wordprocessor that weighs 3.1 pounds and measures 11.75 inches wide by 8.5 inches high by one inch deep. The LCD screen that can display 80 characters by eight lines, and the background can be adjusted to increase readability in any light. At $349.95, the price is less than than the Tandy 102 and there are somewhat different features. Wordprocessing and telecommunications are ROM resident: however, the wordprocesor has been enhanced with a thesaurus and spell checker that will check a specific word or an entire document. The stock 22K RAM can be increased internally to 54K or externally with 32K IC cards that plug into the WP-2. The case has a standard sized keyboard, nine pin RS-232C serial port, a parallel port, a cassette port, and an AC port.

The retail price of the Laser PC3 is $270.00, though it may be purchased from Educational Resources, 1550 Executive Drive, Elgin, IL 60123, 800-624-2926 for $170.00. Weighing one pound, nine ounces and measuring 10 inches wide, 7.6 inches high, and 1.3 inches deep, the PC3 has nine builtin applications including wordprocessing, diary, address list, typing tutor, phone directory, calculator, and spelling checker. The device has a standard sized keyboard, 20 character by two line flat LCD screen (with adjustable background), and serial and parallel ports. Files may be saved to 32 kilobytes of battery backed RAM. The wordprocessing program is somewhat primitive with no cut and paste capabilities.

The smallest and most lightweight of the four, the Atari Portfolio measures eight inches wide by eight inches high (opened) by 1.25 inches and weighs less than a pound. Priced at $399.00 and available from Atari Corporation Portfolio Department, PO Box 61657, Sunnyvale, CA 94088, 800-443-8020, the Portfolio has a flip-up super-twist LCD screen that displays 40 characters by 8 lines; a keyboard made of small keys that are difficult to activate; and an expansion port that with the appropriate cable can interface to parallel and serial ports. The parallel and serial interfaces are optional and must be purchased separately. There are six builtin programs including spreadsheet, wordprocessing, phone/address directory, calendar, and calculator. The Portfolio comes with 128 kilobytes of RAM and utilizes RAM memory cards (32K, 64K, and 128K) to store additional work.

DISCUSSION

Each of the four devices may be interfaced to a school printer to become an alternative writing system; however, one of the four machines will be the optimal match for S. In the decision for S.'s alternative writing device, the PC3 was eliminated because of the lack of cut and paste wordprocessing capabilities, and the Portfolio because of key size and key strike characteristics. Of the two remaining machines, the Tandy 102 and the WP-2 were compared for features and the Tandy 102 was eliminated because of the higher price, features that were not needed, and features that were not available. For S. the 3.1 pound WP-2 from Radio Shack was determined to have the best value, a combination of price and wordprocessing features including cut and paste capabilities, spelling checker, and thesaurus. Since Radio Shack has an educational discount, the device was purchased for less than $300.00. When the alternative writing device arrives, the training process, developed in conjunction with school personnel and family members, will begin.

ACKNOWLEDGEMENTS

This work was supported by All Children's Hospital, St. Petersburg, FL; Franklin-Jefferson Counties Special Education District, Benton, IL; Mamie O. Stookey School, Belleville, IL; Coleman Tri-County Services, Harrisburg, IL; Williamson County Special Education District, Marion, IL; and Bissell Healthcare Corporation, Grand Rapids, MI.

Aimee J. Luebben
Community Services
503 Freeburg Avenue
Belleville, IL 62220
618-235-8460

11.7

DIRECT MULTI-SWITCH KEY SELECTION

PER KROGH HANSEN
POINTER SYSTEMS INC.

1. ABSTRACT

Direct Multi-Switch Key Selection (DMSKS) is a new computer access method for the disabled user capable of using five or more switches. A five by five matrix containing "keys" is displayed on part of the computer's screen. The five switches are numbered one to five. The user must press the row number and then the column number, in order to input the wanted "key". Vast speed improvement is achieved.

2. BACKGROUND

Switch type input methods for computer access by the disabled user are not new. One or two switches have been used for many years in combination with various scanning techniques. Many improvement schemes have been developed and utilized, but scanning is still very slow, when compared to an able-bodied person inputting from the keyboard using all ten fingers. More than two switches and/or switch type joysticks have been used in combination with scanning, but only small speed improvements have been achieved. Keyguards and "single-finger" software programs has been designed and developed in order to help the disabled user utilize a "hunt and peck" kind of use of the keyboard with one or two fingers.

3. STATEMENT OF THE PROBLEM

The keyboard on the computer constitutes a substantial barrier for physically disabled persons. A problem exists today for the disabled person, who can select keys from the keyboard, but simply does not have the range of motion to utilize the whole keyboard. This person can utilize more than two switches. The scanning systems with one or two switches are in most cases painfully slow and do not fully utilize these people's abilities.

4. RATIONALE

The disabled user who can use more than two switches, but still not access the whole keyboard today must settle for slow input speed when using computer access systems. A faster method, the DMSKS, was developed in order to facilitate a faster input speed and the utilization of all of these people's abilities. The input of two digits for each "key" (letter or word) gives the user a faster computer access system. The DMSKS is a preferable choice for the disabled user capable of more than two switch scanning, but not capable of full keyboard access.

5. DESIGN

The user uses five switches numbered one to five. The switches are placed so that the disabled user has easy access to them all. Part of the computer screen is taken up by a five by five keyboard "key" matrix. The first matrix is filled with the first 24 letters and "space". Each "key" has two numbers, the first identifying the row and the second identifying the column. In order for the user to input the wanted "key" into the computer's application software, the user must simply press first the row number by selecting the switch which has the number in which the wanted "key" appears. The software in the computer then lights up this row. The user then selects the "key" by selecting the corresponding column's numbered switch. This "key" is then input to the application software running in the computer, as if the corresponding key was pressed on the computer keyboard.

The user can also easily change to the second "key" matrix containing the reminder of the letters in the alphabet, the numbers and some signs, by simply holding down switch number two longer than a predetermined time. The third "key" matrix contains all the shift "keys" and is accessed by the user by holding down switch number Three longer than a predetermined time. The Fourth "key" matrix contains all the function keys and the reminder of the signs and shift "keys". It is accessed by the user by holding down switch number four longer than a predetermined time. The Fifth "key" matrix contains a number of the most common words. It is used to display the words for word prediction after the user has selected a letter. It is accessed by the user by holding down switch number five longer than a predetermined time.

The user can access the twenty five "keys" displayed in the matrix on part of the screen by simply pressing the row number and then the column number. It is easy for the user to shift between which of the five "key" matrixes he/she wants to select from. Thus the user has direct switch access to 125 "keys".

6. DEVELOPMENT

The DMSKS computer access system has been implemented into a full fledged computer access software package. The DMSKS software includes the standard features such as Wordprediction, Logical letter coding, automatic word endings, help menus, parameter option settings etc.

7. EVALUATION

Evaluation of the DMSKS software has been evaluated for computer access only. This evaluation used only five switches and therefore a five by five "key" matrix organization. In order to compare DMSKS software to simple row/column scanning consider a five by five "key" matrix, where all "keys" are being used equally. For simple row/column scanning this matrix then represents 125 time ticks. The DMSKS represents 50 time ticks. Which shows a 250% speed increase. Evaluation has show that the DMSKS is very intuitive for the user. Only a short introduction was necessary, if the user had used the computer and a computer access system before. The introduction was simply to introduce the different "key" matrix screen displays and the row and column numbering. It is possible that the DMSKS software is faster to use for a disabled user than to use simple "hunt and pick" with one or two fingers. It is possible to use five keys on the computer keyboards for the five switches. It is clear that using more than five switches will allow the user to have larger "key" matrixes. The user can therefore access more "keys" directly without switching between "key" matrix display screens. Advanced users could obtain even higher speeds by simply always lighting up the first row of the "key" matrix and thereby allowing the user to input any of the "keys" in the first row by only one switch selection. This was achieved by simply monitoring, if a second switch was selected within a predetermined time delay.

8. DISCUSSION

The multi switch input method, DMSKS, described here offers a vastly improved speed performance for the person, who can use at least five switches. It further encourages the user to use all five switches and thereby makes sure that the persons range of motion does not become more limited. The user also needs to stay active at all times, which will encourage participation. The operation of this system is very intuitive and the user does not need much training, before he/she is up and running. The system can be compared to the Morse code input method. It does, however, have a much more intuitive encoding and it always appears on the screen in front of the user.

This input method can be used for augmentative communication where speech communication is necessary. The technique described here can be used to improve any existing augmentative and computer access system already on the market. It does however lend itself best for use in the computer access systems, since the computer has the flexibility to very easily change the "key" matrix size. It is also very easy to place different letters, signs, numbers, words or functions into the different "key" in the matrix.

Per Krogh Hansen
Pointer Systems Inc.
One Mill Street
Burlington, Vermont 05401

11.8

PRELIMINARY STUDIES FOR A SIMPLE PERSONALISED COMPUTER INTERFACE USING VOICE/SOUND RECOGNITION TO FACILITATE COMMUNICATION AND ENVIRONMENTAL CONTROL FOR SEVERELY DISABLED DYSARTHRIC INDIVIDUALS

David A Boonzaier and Ari Limon

Rehabilitation Technology, Biomedical Engineering Department,
University of Cape Town & Groote Schuur Hospital

ABSTRACT

This project involves the design and development of a low-cost voice-activated computer interface for severely physically disabled people. The primary objective of this project is to design a system with automatic "translation" which will allow a subject to use utterances (often unintelligable to an unfamiliar listener) to enhance communication, and to facilitate interaction with computer-based devices in the environment. This system would be of tremendous benefit to members of this population who are capable of producing consistently repeatable, but non-verbal utterances. In the past these people have only been able to communicate via simple manual devices such as two-state (yes/no) switches; this has thus far severely limited their communicative ability.

BACKGROUND

People who as a result of neurological trauma and/or disease are paralyzed or unable to exercise fine control of their body, may nevertheless retain the ability to communicate by oral sounds. In some cases the patient may have full articulatory control; however, in other cases he or she may only be able to produce unintelligible sounds. It is the people in this latter group who are of concern to us here. Their disabilities may be the result of many conditions, e.g.,

a) cerebral palsy,
b) head injury,
c) cerebral vascular accident (CVA),
d) brain stem injury, and
e) amyotrophic lateral sclerosis (ALS or Lou Gehrig's Disease), or other progressive myo-neural diseases.

Many who retain complete intellectual capacity are greatly restricted in their ability to communicate with other people, and to exert physical control over their environment. This predicament remains a great source of frustration for patients, and often leads to severe depression and withdrawal. The essential problem posed, therefore, is how to successfully exploit the residual vocal ability of these patients, to provide them with an efficient channel for communication and environmental control.

The pivotal focus of the project is the development of a system for use by cerebral palsied children, however, results obtained may be universally applicable to handicapped individuals with aetiologies mentioned above.

The voice controlled computer interface will take as input, samples of sounds produced by the patient, and generate as output, messages, or address-codes to activate devices. Essentially, the interface acts as an interpreter: translating the sounds produced by the patient, unintelligible to other humans, into positive actions performed by the computer, including communication with others. The system differs from other commercially available speech recognition systems in that it contains only the bare minimum of speech processing hardware and software required to execute what is essentially an extremely rudimentary "speech" recognition task; thereby, keeping overall cost to a minimum, and facilitating the proliferation of such devices.

SYSTEM DESIGN AND FEATURES

The voice processing system is designed using a digital signal processing (DSP) development system, in the form of a plug-in card for an IBM PC compatible computer. Such a development system facilitates efficient prototyping and testing of DSP software designs. The development optimised speech recognition algorithm.

Once the development of the interface has been completed, using the development system, the design of a stand-alone device will be undertaken. This device, possibly in the form of a plug-in card for an IBM PC compatible computer (or perhaps a portable lap-top PC), will contain only the necessary hardware and software required to implement the proposed interface. The design of a stand-alone device will greatly reduce the cost of the device and offers the advantages of portability.

In practice the system will be "trained" to recognize a unique set of sounds for a particular subject. Once the training routine is completed, the computer will be able to accurately identify spoken commands, and act on them. It is an essential requirement of the system that it be able to respond to a spoken command in real-time (or near real-time). If the lag-time between command and response is too great, the communication/control feedback loop is effectively broken; the system would, therefore, be ineffectual to the user. Feedback, in the form of graphic or audio output from the computer, must be provided to the user, in order to acknowledge receipt of command input, and to verify its successful execution.

Unique utterances will provide the user with access to a selection matrix displayed on the host computer screen. The user will select the desired operation or function from the matrix. Numerous levels of matrices may be superimposed, providing many more possible selections using the same basic set of sounds. Possible selections may include generation of synthesized spoken (or typed) messages, or control of devices (e.g., radio, television, telephone, computer software, and other ADL tasks).

ASSESSMENT OF VOCAL ABILITY

The first stage of the project involves carrying out a comprehensive assessment of the vocal abilities of a range of physically disabled individuals. The assessment of the individuals in the above mentioned categories, involves, determining the number of different sounds, that an individual can reproduce, which are differentiable with respect to pitch, magnitude, and other audio spectral features; and further, establishing whether an individual can learn to reproduce a particular, or even extended, set of sounds (which could act as a "vocabulary" of vocal commands), i.e., the encouragement of the individual to produce a machine-recognisable metalanguage.

Articulatory assessment tests have been performed with the help of qualified speech therapists, on a group of nine cerebral palsied children. The children vary in age from 4 to 10 years. They have varying degrees of spasticity, and have no mental retardation. Results of the tests on these children indicate that they all exhibit sufficient articulatory control to reproduce "open mouth" (laryngeal) vowel sounds. The more dysarthric children had greater difficulty with sounds requiring lip closure. These tests have shown that non-verbal children are capable of reproducing a set of sounds (particularly vowel sounds) that could act as a "vocabulary" of audio-input commands to a computer.

CONCLUSIONS

The envisaged system will, we believe, greatly improve the efficiency of communication for severely disabled individuals who retain some vocal ability. The system has the potential of providing benefit to a large number of people with different pathologies.

REFERENCES

BOONZAIER DA, ENGELHARDT KG, AWAD-EDWARDS R
1985
Interactive Evaluation of Current Voice Input Technology for the Physically Disabled Suggests New Avenues for Continued Research.
RESNA 8th Annual Conference, Memphis, Tenessee.

BUCKLEY R
1988
The Use of Sound-to-Speech Translation and Expansion with Children and Adults who are Mentally Retarded.
RESNA ICAART 1988, Montreal.

MANGOLD H
1988
Principles of automatic processing of speech signals and their application in medical technology and for aids for handicapped.
Medical Progress through Technology 14:39-56.

ROSEN MJ, GOODENOUGH-TREPAGNIER C
1982
Communication Systems for the Non-Vocal Motor Handicapped: Practice & Prospects.
pp. 31-35: IEEE Engineering in Medicine and Biology Magazine, 1982 December.

First author's address:

Dr David A Boonzaier
Director, Rehabilitation Technology
Biomedical Engineering Department
University of Cape Town Medical School
Anzio Road
Observatory 7925
Cape Town
South Africa

Rural Assistive Technology Services: The Montana Adaptive Equipment Program

Roxanne Hiesterman, OTR/L
St. Peter's Community Hospital
Helena, Montana

INTRODUCTION

Providing rural assistive technology services in Montana over the past decade has required the same pioneering spirit and determination as that of early settlers who established networks of trade routes, and other links between people with common concerns. In spite of the challenges of distance, weather, limited resources and therapists, outreach services have developed. Two-hundred and eighty developmentally disabled clients are dispersed in cities, isolated towns and on Indian reservations across an expansive state of 145,392 square miles, populated by 850,000 people. The need to provide adaptive equipment to clients under these circumstances has created a model of decentralized rural technology services coordinated by a central office and staff.

HISTORY

The Montana Adaptive Equipment Program, a technology service delivery program, was established to provide specialized adaptive seating and positioning, mobility, and self-care equipment and program consultation to multiply handicapped developmentally disabled individuals in the state of Montana. Since 1975, The Developmental Disabilities Division of the state Social and Rehabilitation Services has contracted with various agencies to deliver these grant funded services. A physical therapist founded and served the state-wide program for five years. Between 1980 and 1986 the concept of contracting with outreach therapists was initiated and the number of therapists increased from 1 to 6, dispersed throughout Montana. In 1987, our institution in Helena became administratively responsible for the Grant. The Program merged with the Pediatric Neurology Service offering a state-wide referral base and medical link.

METHODS

Evaluation of client/family equipment needs is currently determined by 12 contracting physical or occupational therapists throughout Montana. Each outreach therapist is also responsible for requisition, delivery and fitting of physician-approved equipment. Coordination of all state-wide outreach services takes place at a central office in the Neuroscience Department of our institution by the Clinical Outreach Coordinator. As case manager, the coordinator reviews the need for equipment and available funding. The Montana Adaptive Equipment Program (MAEP) office staff confirms developmental disability eligibility on all referrals, preauthorize, order and bill equipment. Other services offered to outreach therapists include an equipment loan pool and staff development program.

Referral to the adaptive equipment program is made by families and local professionals with appropriate documentation of client's developmental disability. The definition of developmental disabilities used by the Developmental Disabilities Division varies from the federal definition, which at the time is used only by the agencies funded under P.L. 100-146. According to Montana Codes Annotated, Title 53, Chapter 20 Part 202, Montana's definition of developmental disabilities specifies that:

> Developmental disabilities means disabilities attributable to mental retardation, cerebral palsy, epilepsy, autism, or any other neurologic handicapping condition closely related to mental retardation and requiring treatment similar to that required by mentally retarded individuals if the disability originated before the person attained age 18, has continued or can be expected to continue indefinitely, and constitutes a substantial handicap for the person.

Services are delivered by therapists primarily in the client's living environments to insure appropriate and realistic recommendations for equipment. Outreach therapists utilize the expertise of other professionals i.e. school therapists, child and family service providers, Durable Medical Equipment (DME) specialist and vendors by scheduling team visits for evaluation and delivery of equipment. This communication network on positioning needs and equipment service is an effective way to reduce time and costs expended. It eliminates excessive visits and purchase of unnecessary and inappropriate equipment.

To repair or replace specialized equipment, the Montana Adaptive Equipment Program issues purchase orders with specific instructions to the Durable Medical Equipment specialist or local suppliers of equipment. A DME specialist, on contract with the Program, routinely travels throughout Montana every 6 to 8 weeks. Outreach therapists inform the central office of necessary service calls which are then scheduled in a systematic manner by geographic location. Emergency repairs, not under warranty, are scheduled by the vendor who is nearest in proximity.

Reimbursement to outreach therapists and DME specialist is made per client visit with additional compensation for indirect service time (calls and arrangements), mileage, travel time, phone and postage expenses. Contract employees of the program are responsible for their own licensing and liability fees.

Funding for services and equipment may come from more than one source. Medicaid or private insurance must be utilized prior to accessing the Adaptive Equipment Grant. To insure coverage of insurance claims, equipment is preauthorized. According to MAEP policy, clients or their families are not billed directly for equipment or services.

Inservice sessions for the MAEP outreach specialists are held at the central office every three months. Presentations by therapists or guest speakers offer information on theory and application of assistive technology, equipment update, and service delivery to the multi-handicapped client. Meetings are videotaped for the the Program's library and are available to therapists on request. Therapists are also encouraged to attend one out-of-state workshop per year. To improve the quality of service and networking to clients, the Montana Adaptive Equipment Program periodically offers educational opportunities to other interested professionals.

The annual budget of this hospital based state wide technology program is approximately $208,200. Funding by the Montana Adaptive Equipment Grant to administer the grant, pay therapists and employees, purchase and repair equipment, is matched by our institution.

SUMMARY

Through a state-wide network of occupational and physical therapists, coordinated by a central office, assistive technology services are delivered to clients in their home community. Montana Adaptive Equipment Program Specialists collaborate with an extended network of local rehabilitation professionals to assure quality, cost effective services. In Montana, interdisciplinary communication is essential to the efficiency of the Program.

ACKNOWLEDGEMENTS

We would like to acknowledge Jan Hulme, P.T. and Leslie Mulette, OTR/L who founded and developed the Montana Adaptive Equipment Program.

Funding is provided by St. Peter's Community Hospital and the Montana Department of Social and Rehabilitation Services.

ADDITIONAL INFORMATION

Additional information may be obtained by contacting :

Montana Adaptive Equipment Program
Department of Neurosciences
St. Peter's Community Hospital
2475 Broadway
Helena, Montana 59601

12.2

AGRICULTURAL WORKSITE ACCESSIBILITY FOR FARMERS AND RANCHERS WITH SPINAL CORD INJURIES

Harry W. Cook, Gregory W. Schnepf and William E. Field
Breaking New Ground Resource Center
Agricultural Engineering Department
Purdue University, West Lafayette, IN U.S.A.

ABSTRACT

With support from the ***Paralyzed Veterans of America Spinal Cord Research Foundation, The Breaking New Ground Resource Center*** is conducting an investigation into the needs of farmers with spinal cord injuries. Over 250 farmers have participated in the study including over 50 who agreed to participate in an on-site worksite needs assessment. The findings from the study will be used to develop resource material designed to assist farmers who experience spinal cord injuries to make appropriate accommodations to their existing operation or to evaluate alternative opportunities.

INTRODUCTION

An estimated 5000-6000 individuals with spinal cord injuries reside on this country's farms and ranches. Many of these people provide meaningful input to the daily operation of farms and ranches and have demonstrated that a spinal cord injury does not necessarily mean the end of a career in agricultural production. Through the use of a wide variety of ingenious, often home-made, modifications to agricultural equipment, tools and facilities, many essential agricultural production-related tasks have been made accessible. However, as with most rural residents, farmers with spinal cord injuries have yet to fully realize many of the potential benefits of recent advances in the field of assistive technology due to their isolation, lack of comprehensive rural rehabilitation services, limited financial resources and numerous other complex reasons. To better understand the special vocational needs of farmers and ranchers with spinal cord injuries, the ***Breaking New Ground Resources Center***, with support from the ***Paralyzed Veterans of America***, initiated a study entitled "Rehabilitation Technology Needs Assessment of Farmers and Ranchers with Spinal Cord Injuries". The study has two primary goals.

1. Develop an estimate of the number of individuals with spinal cord injuries who live and/or work on American farms and ranches or who are involved in some aspect of agricultural production. Included are attempts to determine population distribution and projected population changes.

2. Complete a comprehensive rehabilitation technology needs assessment, with a special emphasis on worksite accessibility, of individuals with spinal cord injuries living in rural areas, on farms and ranches and involved in agricultural production.

METHODS

The study involved over 250 spinal cord injured farmers and ranchers who have contacted the ***Breaking New Ground Resource Center*** over the past 10 years. A survey instrument was developed that was designed to gather information on both vocational and personal independent living needs of the target population. The survey was mailed to each participant with an offer of a small gift to those willing to complete and return the form. Usable surveys were received from 131 individuals or slightly over 50 percent of those surveyed. Responses were received from 22 states and several Canadian provinces.

In addition, over 50 of the farmers or ranchers agreed to participate in on-site visits. These visits were used to expand on the survey questions and to document the needs that were considered important to participants. Each on-site visit resulted in a written case history that included photographs documenting the nature of the farm -operation, type of enterprises and modifications that have been made to accommodate the farmer's disability. These on-site visits took place in 9 states.

FINDINGS

Of the 131 responders to the survey, 68 percent had experienced paraplegia and 32 percent quadriplegia. Over 95 percent were male and 57 percent were under the age of 30. Nearly 13 percent were over the age of 60.

Regarding vocational activities, 24 percent considered themselves to be full-time farm operators with another 9 percent listing the farm as their primary source of income. Thirty-two percent listed an off-farm job as their primary source of income and only 9 percent considered themselves as unemployed.

Hay, corn, and range/pasture were the most common usage of the responders acreage with 48 percent of those raising corn having less than 100 acres. Beef cattle were being raised twice as often as any other livestock. The majority of farmers raising beef, raised less than 100 head.

Responders remain active in the day-to-day activities of the farm/ranch with 70 percent involved with sales and purchases, farm business records, and labor management. In 60 percent of the cases, family members were listed as assisting in these and other farm/ranch related tasks. The degree of assistance needed is reflected in Table 1 which shows the respondents' ability to do particular farm/ranch related tasks. The most difficult tasks or those requiring assistance related to the use of machinery and handling of livestock. For example, 79 percent required assistance to repair heavy farm equipment such as tillage implements and over 83 percent needed help to load livestock onto trucks for delivery to market.

Table 1. Difficulty of Various Farm/Ranch Related Activities.

	No Difficulty	Some Difficulty	Difficult	Very Difficult	Need Help
Accessing farm buildings	10.6%	50.5%	22.1%	5.3%	11.5%
Accessing fields to check field work, crops, etc.	18.2	48.2	19.1	1.8	12.7
Accessing tractor, etc.	12.9	32.6	11.9	4.0	38.6
Hitching implements	3.3	3.3	17.8	5.6	70.0
Operating tractor and combine controls	48.7	41.5	9.8	--	--
Fueling and maintenance of tractors, etc.	4.2	18.7	17.7	5.2	54.2
Routine machinery maintenance and repair	4.2	24.2	14.7	5.3	51.6
Repairing heavy machinery	1.1	2.2	9.8	7.6	79.3
Welding	11.8	21.2	11.7	4.7	50.6
Couping hydraulic lines	13.4	18.3	9.7	9.8	48.8
Making PTO connections	9.6	15.7	18.1	6.0	50.6
Moving grain or concent. to feed livestock	2.8	12.7	14.1	1.4	69.0
Feeding hay to stock	5.7	17.1	12.9	2.9	61.4
Loading or moving livestock	1.3	3.8	7.7	3.8	83.4
Opening and closing barn doors, gates, etc.	9.1	33.0	19.2	11.4	27.3
Cleaning barns	1.5	13.9	9.2	4.6	70.8
Milking	2.5	10.0	10.0	2.5	75.0
Mowing the lawn	43.8	21.3	7.9	2.2	24.8
Cleaning milkhouse and equip	--	8.3	8.3	--	83.4
Attending to the medical needs of stock	3.3	11.7	5.0	5.0	75.0
Feeding and watering young stock	15.3	6.8	10.2	8.5	59.2
Castration/docking tails/clipping teeth	3.6	7.1	3.6	1.8	83.9
Gardening	8.5	24.4	20.7	12.2	34.2
Maintaining the orchard	5.0	10.0	20.0	6.7	58.3
Harvesting logs or splitting wood	1.6	6.3	7.9	7.9	76.3
Maintaining farm bldgs.	--	9.5	10.7	6.0	73.8
Using farm shop tools	21.4	35.9	14.6	8.7	19.4

These individuals were also asked about their involvement in various community and personal activities. Church and farm organizations were the most often attended activities with 65 and 50 percent, respectively. Sports and school involvement were the activities least involved in.

Nearly 90 percent of the farmers were licensed to drive with 80 percent feeling very comfortable with respect to their driving situation. Nearly one-third reported that they used a pick-up truck as their primary means of transportation. Over 37 percent lived more than 51 miles from the nearest source of rehabilitation services.

Accessibility of various public facilities was looked at with more than 75 percent of the responses indicating at least partial accessibility. Banks and grocery/clothing stores had the greatest level of accessibility while post offices and libraries presented the greatest number of barriers.

Farmers and ranchers were finally asked to prioritize their goals concerning worksite accessibility. The two most often mentioned goals were:

1. Improve overall mobility or accessibility around farmyard, buildings, and fields.
2. Improve ability to effectively and safely use equipment and machinery, including accessing, operating, and maintaining equipment and hitching implements.

SUMMARY

The findings clearly demonstrate that individuals with spinal cord injuries, especially paraplegia, are able to continue farming successfully. In most cases modifications to the worksite are needed and there is often a move towards an increased management role. It is anticipated that the solutions identified to improve the independent living skills of this population will have spin-off benefits for other individuals with spinal cord injuries.

ACKNOWLEDGEMENTS

Aided by a grant from the ***Paralyzed Veterans of America Spinal Cord Research Foundation.***

W.E. Field
1146 Agricultural Engineering Bldg.
Purdue University
West Lafayette, IN 47907-1146

Mobile Rural Assistive Technology Unit

Therese M. Willkomm
Easter Seal Society's FaRM Program
Des Moines, IA.

Abstract:

This paper focuses on a Mobile Rural Assistive Technology Unit developed and implemented to provide onsite assistive technology services for Iowa farm families affected by physical disabilities in achieving maximum independence in performing vocational and independent living activities.

Background:

Farming as a way of life can be very challenging for over 37,000 Iowa farm families affected by permanent physical disabilities including amputations, spinal cord injuries, back injuries, arthritis, respiratory impairments, neuromuscular disorders, and other disabling conditions. During the past 4 years, the FaRM Program has provided assistive technology services related to agricultural worksite modifications and independent living adaptations, to over 350 Iowa farm families. Providing adaptive equipment or modifications in rural areas can be very time consuming and expensive. Many of the adaptations are constructed by volunteers, local machine shops, and the FaRM Program staff. The types of adaptations/modifications include: modifications to tractors for farmers with mobility restrictions; modifications to livestock handling facilities; hand tool adaptations; prosthetic adaptations; adaptive independent living aids; and modifications to the farm home and farm buildings.

After an agricultural worksite assessment is completed, the necessary modifications or adaptive equipment is designed and constructed on off farm sites throughout the state. Many of these adaptations were constructed several hundred miles from where the farmer lives. The completed modification was then brought to the farm for the farmer to use. If the modification did not work, it was brought back to the shop for necessary revisions and then taken back to the farmer. This process can take three to six months of unnecessary time delay, not to mention the travel costs and staff time. In addition, this time delay has a direct economic effect on the farmer's ability to return to farming. Often, farm families have little money to hire additional help while needed adaptions are being made. Spring planting and fall harvest cannot wait three months. Furthermore, due to financial limitations, many individuals go without or have inadequate assistive technologies which result in secondary injuries or injuries to family members and co-workers.

Objective:

To overcome these barriers, the Easter Seal Society of Iowa's Farm Family Rehabilitation Management Program (FaRM) developed and implemented a Mobile Rural Assistive Technology Unit that would construct, onsite, needed assistive technologies that enables farmers affected by physical disabilities to return to farming and independent living.

Methods:

Vehicle Selection, Modification, and Operations:

Existing Mobile Rehabilitation Engineering Units operated by: United Cerebral Palsy Foundation in Witchita Kansas, the United Cerebral Palsy Foundation in New Jersey, and the Woodrow Wilson Hospital in Virginia, were contacted to obtain input and ideas in developing a mobile unit to accommodate the unique needs of Iowa farm families. As a result, a proposal was submitted and received from the Dole Foundation for the Employment of People With Disabilities, to purchase a 1990 3/4 ton Chevy van with a 350 engine. This van was modified with a 2 foot raised roof, captain chairs for rider comfort, and a bulk head for safety. Tool cabinets and a workbench, obtained from government surplus, were mounted to the sides and floor of the van. An invertor was also installed so that lighting and other basic hand tools could be operated while the van was running.

A grant received from the Rehabilitation Services Administration, funded the van operations costs and a rural rehabilitation technologist to operate the unit. Additional funding for this unit was obtained through Casey's General Stores, Inc. in Iowa and the Iowa Farm Bureau.

Tools, Equipment, and Material Selection:

An assortment of hand tools and power tools were purchased and placed inside the van. The most frequently used power tools included a 14" chop saw, a 100 volt portable mig welder, a bench and hand grinder, a vice, drill, circular saw, and electric post hole digger.

Additional tools, equipment, and materials obtained included: an oxygen-acetelyne torch, a 220 volt arc welder, portable work bench, saw horses, an assortment of fasteners and adhesives, and an assortment of round bar stock, flat bar stock, grip strut, expanded metal, and square steel tubing.

Ongoing Funding:

Funding for the operating costs of this unit has been obtained through grants from agricultural related businesses, foundations, individual donations, and public grants. Obtaining ongoing funding for this unit will continue to be a challenge due to the unique nature of individuals served who are not covered by wage loss insurance and whose specific technology needs are not considered medically necessary.

In November of 1990, the mobile unit was expanded to include a 16' trailer to transport larger fabrication materials & equipment and for conducting rural assistive technology clinics.

Results:

During the past year, a total of 246 rural assistive technology solutions were developed or obtained for 102 farm families. The total material retail value of these technologies was $116,000 with an average cost of $450 per solution. The mobile rural assistive technology unit was involved in providing approximately 50% of these solutions. Of the solutions provided: 37% were used to perform farm related tasks; 41% to perform independent living tasks; 6% to perform therapeutic exercises; and 17% to perform personal care activities which include mobility aids and prosthetic devices.

The level of accommodation used in solving a problem task included: 10% through job restructuring or alternative techniques for accomplishing the task; 42% through obtaining a commercially available technology; 13% through modifications of commercially available items; and 35% through design and fabrication of a new assistive technology related solution.

This unit was made possible be a grant from The Dole Foundation for the Employment of People With Disabilities, and The U.S. Department of Education, Rehabilitation Services Administration-Grant #H128A91136-89.

For more information contact:

Therese Willkomm, Director
Easter Seal Society of Iowa FaRM Program
P.O. Box 4002
Des Moines, Iowa 50333
(515) 289-1933.

ALTERNATIVE AGRICULTURAL ENTERPRISES FOR FARMERS WITH PHYSICAL DISABILITIES

Lauri K. Logan, Project Coordinator, Edward J. Sheldon, Research Assistant
Breaking New Ground Resource Center
Department of Agricultural Engineering
Purdue University, West Lafayette, IN U.S.A.

INTRODUCTION

In 1989, the Departments of Agricultural Engineering and Agricultural Economics at Purdue University began a study entitled "Rural Job Development and Job Placement for Farmers with Physical Disabilities." The three year study is funded by the United States Department of Education's National Institute on Disability and Rehabilitation Research. The project is designed to examine problems faced by rural residents with physical disabilities, and to develop a better understanding of the impact of disabilities on rural families. This paper will deal with the facet of the project relating to the use of alternative income sources on the farm by farmers with physical disabilities. The Breaking New Ground Resource Center at Purdue, as well as the Iowa Easter Seals' Farm Family Rehabilitation Management Project (FaRM), will participate in the completion of the study.

For purposes of this study, an alternative agricultural enterprise includes non-traditional farm enterprises or farm diversification, as well as on-farm businesses which provide supplemental income. The findings of the study should help to develop the resources needed to establish successful farm-based alternative enterprises and the associated assistive technology as a viable income generating source for farmers with physical disabilities.

METHODS

An initial step of the study consisted of a mail survey sent to approximately 1700 physically disabled farmers on the Breaking New Ground mailing list. The survey documented their employment experiences and efforts to establish alternative farm-based enterprises. Included in the survey was information regarding off-farm employment, their farm operation, and any alternative enterprises which may be in use. Also, the participants were asked to specify barriers which prevent or hindered their ability to complete necessary job-related tasks.

After the data from the survey has been thoroughly examined, a group of 50 farmers with alternative on-farm enterprises will be selected for on-site visits. During these visits, case histories will be developed, documenting the enterprise and assistive technology used by the operator. From the information gained from the survey and case histories, resource materials will be developed to guide those people interested in starting alternative enterprises, including a publication containing case histories of the farmers visited. These materials will be designed to assist farmers, and rural rehabilitation professionals in the choice, start-up, and development of an alternative enterprise. Also, the use of assistive technology in regards to alternative enterprises will be a major focus.

DISCUSSION

Are alternative enterprises a viable option for farmers with physical disabilities?

Approximately fifty percent of the survey respondents indicated an interest in starting alternative income sources on the farm, while nearly 30 percent of the participants reported that they currently utilize such enterprises. Among the more frequently named enterprises included specialty crops and livestock, and service-oriented businesses. When asked to rate various barriers and situations which hinder participation in farm enterprises as well as off-farm employment, the survey participants ranked physical disability as the greatest problem (see Table 1). These results show a need to further examine the resource, and develop strategies to make alternative agricultural enterprises more accessible to farmers with physical disabilities through education and assistive technology.

Table 1. Barriers Faced in Finding Employment
(averages given)

```
                                      Problem
                              No       Minor      Major
                              1          2          3
Inadequate transportation     |          |          |
  (1.4)                       |****      |          |
Long distance to nearest      |          |          |
  job site (1.7)              |*******   |          |
Inaccessible job sites (1.8)  |********  |          |
Attitudes of potential        |          |          |
  employers (1.9)             |********* |          |
Nature of degree of dis-      |          |          |
  ability (2.2)               |**********|**        |
Persons's physical limita-    |          |          |
  tions (2.4)                 |**********|****      |
Unfamiliar with alter-        |          |          |
  native employment           |          |          |
  options (1.9)               |********* |          |
Lack of adequate on-farm      |          |          |
  facilities (2.0)            |**********|          |
```

Many factors contributed to the decision of whether or not farmers participating in the study pursued an alternative, on-farm enterprise. Some factors included: personal and family interests and capabilities, knowledge of viable alternatives, selling capacity of the product/service, feasibility and practicality of production, and financial capabilities.

Farming alternatives were shown to be quite diverse and included such possibilities as nontraditional crops/livestock; service, recreation or tourism enterprises; unconventional production systems such as organic farming or acquaculture; and direct marketing of products.

CASE EXAMPLES

The Breaking New Ground Outreach Program which is the service delivery component of the Breaking New Ground Resource Center has come into contact with many farm families who use alternative, on-farm enterprises to supplement their income. A few examples are provided.

- Louis Smolek has a 400-acre grain farm near San Pierre, Indiana. In 1978, Mr. Smolek's hand became caught in the corn head of his combine. His hand subsequently had to be amputated. Louis also has a hearing impairment.

  In addition to farming, Mr. Smolek has worked as a carpenter and a mason. His shop is located on the farm.

  Louis has made a variety of modifications to hand tools as well as farm machinery which enables him to work independently. Some of these modifications include a means to connect two springs using one hand, a "handle" for his lawn trimmer, and a cup instead of a ball to operate the hand controls on his backhoe.

- Ed Bell and his wife, Debbie, manage a 72-acre farm near Hagerstown, Indiana. Among other on-farm involvements, the Bells sell freshly-picked produce directly to local customers and through retail outlets.

  When Ed was 21 years old, he became the victim of a gunshot wound which resulted in spinal cord level T-1 paraplegia.

  Mr. Bell's machinery has been modified to accommodate his disability. He has installed hand controls and high-back seats with seat belts on his tractors. Ed uses both a manual and motorized wheelchair for mobility in his house and around the farm. Mr. Bell also has a radio, which he has with him at all times, for communication purposes.

ADDITIONAL SOURCES OF INFORMATION

Information about alternative, on-farm enterprises is available from a variety of resources. Some of these resources include: agricultural universities including the cooperative extension service, sustainable agricultural associations within the state, associations related to a specific enterprise and visiting a farmer involved in the desired activity. In addition, the following agencies may be of assistance:

A.T.T.R.A. (Appropriate Technology
Transfer for Rural Areas)
P.O. Box 3657
Fayetteville, AR 72702
(800) 346-9140
Alternative Farming Systems Information Center
U.S. Dept. of Agriculture
National Agriculture Library
Beltsville, MD 20705
(301) 344-3704

Institute for Alternative Agriculture, Inc.
9200 Edmonston Rd., Suite 117
Greenbelt, MD 20770
(301) 441-8777

Lauri K. Logan, Project Coordinator
Purdue University
Breaking New Ground Resource Center
1146 Agricultural Engineering Bldg.
West Lafayette, IN 47907-1146

Guidelines for the Design of Consumer Products to Increase their Accessibility to Persons with Disabilities

Gregg C. Vanderheiden
Trace R&D Center
University of Wisconsin-Madison
Katherine R. Vanderheiden
Independent Consultant

Abstract

A significant portion of our population (over thirty million in the U.S.[1]) has disabilities which impair their ability to effectively or safely use standard consumer products. This fact and the growing portion of our population which is elderly has focused increased attention on the design of products to make them more accessible. Initial efforts have concentrated on the topic of accessibility of computers and operating systems. Attention is now turning to design of consumer products in general.

In an effort to facilitate this process, a cooperative effort has been launched with industry to develop "Guidelines for the Design of Consumer Products to Increase their Accessibility to Persons with Disabilities." An initial draft of the Design Guidelines has been compiled and is currently undergoing review by industry, consumers, and researchers.

Background

Beginning in 1984, joint government/industry efforts have attempted to address the accessibility of standard computer hardware and software by persons with disabilities. One of the major results of these efforts was the development of design guidelines for use by computer manufacturers and software developers[2]. These guidelines were prepared at the request of the computer industries to assist them in better understanding the accessibility problems in computer design and to identify commercially practical strategies for making their products more accessible. The guidelines were developed using a co-operative industry-consumer-researcher-government consortium in order to provide the best information from all angles. The resulting guidelines ("Considerations in the Design of Computers and Operating Systems to Increase Their Accessibility to Persons with Disabilities") have been used by most major computer manufacturers in their ongoing efforts to make their products more accessible and usable by persons with all types and degrees of disability. The Considerations document is a working document and as such is continually evolving and improving.

Statement of the Problem

The Consumer Products Design Guidelines represent a similar co-operative effort to develop guidelines for the design of "consumer products." For the purpose of these efforts, consumer products are defined as appliances and other electronic and mechanical devices available to the mass market for use in the home, school, office, or for use by the general public in the community. The purpose of these guidelines is to point out problems encountered by persons with various disabilities in using standard consumer products, and to propose design alternatives which will result in increased usability of standard products by persons with disabilities.

As with the computer guidelines, the Consumer Products Design Guidelines are designed to be purely informational in nature, and are being developed at industry's request to facilitate their efforts in accessible design. They represent the compilation of information from many sources and, as a working document, are under continual revision.

Approach

In order to facilitate use by product design teams, the Design Guidelines are organized functionally rather than by disability area. The functional categories are:

Output/Displays: includes all means of presenting information to the user;

Input/Controls: includes keyboards and all other means of communicating to the device;

Manipulations: i.e., all actions that must be directly performed by a person in concert with the device or for routine maintenance; e.g., inserting disk, loading tape, changing ink cartridge;

Documentation: primarily operating instructions; and

Safety: including alarms, protection from harm.

Each guideline is phrased as an objective, followed by a statement of the problem(s) faced by persons with disabilities. The problem statement is accompanied by more specific examples. Next, "design options and ideas" are presented to provide some suggestions as to how the objective could be achieved. Readers are encouraged to think of other ideas. Finally, additional data and specific information is presented at the end of each guideline.

The guidelines are stated as generically as possible. Therefore, all, some or none of the design options and ideas presented may apply in the case of any specific product. The recommended approach is to implement those options which together go the longest way toward achieving the objective of the guideline for the product under design. It is understood that this is not an ideal world, so it may currently be too expensive to implement all those ideas which would best achieve the objective. It is also anticipated that there will be other ways of meeting accessibility objectives than those discussed in the Design Guidelines, and such discoveries are encouraged.

---

[1] Of the total U.S. noninstitutionalized population, 14.1%, or 32.5 million persons, report some activity limitation due to chronic health conditions. From the National Health Interview Survey, 1983-1985. (LaPlante, 1988).

[2] "Considerations in the Design of Computers and Operating Systems to Increase their Accessibility to Persons with Disabilities," original release dated April 1986, a working document of the Design Considerations Task Force of the Industry/Government Cooperative Initiative on Computer Accessibility. Copies available from Trace Center, University of Wisconsin-Madison.

Sometimes a solution to a problem for one type of disability may cause a new problem for a person with another type of disability. For example, those with visual impairments may be helped by replacing a visual readout with auditory output, but this would in turn cause a problem for those with hearing impairments. As such situations arise, the Guidelines attempt to highlight them and suggest ways to avoid or minimize any potential conflicts.

The specific design options are presented under the following 21 general design objectives:

Section 1: Output/Displays

O-1. Maximize the number of people who can hear auditory output.

O-2. Provide redundant visual output for all auditory information.

O-3. Ensure that visual output is in an accessible location/orientation.

O-4. Maximize the number of people who can see visual output.

O-5. Provide redundant audio or tactile output for all visual information.

O-6. Maximize the number of people who can understand visual and/or auditory output.

O-7. Avoid display screen flicker or rapid flashing characteristics that could trigger seizures.

Section 2: Input/Controls

I-1. Ensure that controls are physically accessible.

I-2. Ensure that controls are easily locatable.

I-3. Ensure that labelling of controls, keys, etc. is maximally discernable.

I-4. Ensure that the status or setting of the control or other input device is easily discernable.

I-5. Maximize the number of people who can physically operate controls and other input mechanisms.

I-6. Maximize the number of people who can understand how to operate controls and other input mechanisms.

I-7. Facilitate the use of special alternative input devices.

Section 3: Manipulations

M-1. Maximize the number of individuals who can physically insert and/or remove objects as required in operation of a device.

M-2. Maximize the number of persons who can physically grasp and/or open the device.

M-3. Facilitate removal and replacement, or repositioning, of often-used detachable parts.

M-4. Maximize the number of people who can understand how to carry out the manipulations necessary to use the product.

Section 4: Documentation

D-1. Maximize the number of people who can access and understand the documentation.

Section 5: Safety

S-1. Maximize the number of people who can perceive hazard warnings.

S-2. Guard against accidental injury to the user due to unperceived hazards or user's lack of motor control.

Implications and Discussion

Four different approaches to accessible design are discussed in the Guidelines. In any one product, it may be necessary to use one or a combination of these approaches to achieve the desired level of accessibility. These levels, in order of desirability, are:

1. Direct Accessibility
2. Accessibility via Standard Options or Accessories
3. Compatibility with Assistive Devices
4. Facilitation of Special Modifications

Direct Accessibility:

For most types or degrees of impairment, there are simple and low cost (or no cost) adaptations to product designs which can significantly increase their accessibility and usefulness to individuals with functional impairments. By incorporating these design modifications into the initial product design, the standard product can be accessible directly "out of the box."

Inclusion of these design features or approaches in the standard product can be of substantial benefit to society as a whole to the extent it enables these individuals to lead more independent and productive lives. As an additional bonus, it has often been found that designs which are accessible to persons with disabilities may benefit other users (without disabilities or impairments) as well by reducing fatigue, increasing speed or decreasing the number of errors made.

> *An example*. The "Mouse Keys" feature on the Apple Macintosh™ computer was built in to allow the user to move the cursor across the screen via the numeric keypad rather than the mouse. Individuals who do not have the motor control necessary to operate a mouse can use this feature (which is built into all Macintoshes) to access the Macintosh. Because the feature is implemented as an extension to the operating system, it costs nothing to include as part of the product. Since "Mouse Keys" became available, many able-bodied users have found it desirable as well because of its capability of precise one-pixel positioning, which was not previously available.

Accessibility via Standard Options or Accessories:
Sometimes adaptation of the standard product to make it directly accessible is too costly. In other cases, alternatives to standard design are identified, but offering all of them would be uneconomical or perhaps not practical due to some alternatives being mutually exclusive.

When this occurs, it may be most effective to make these adaptations or alternatives available as standard options or accessories. These may be extra-cost, special order items or free items available on request.

> *An example.* Microwave ovens are often made with smooth control panels: that is, there are no tactilely discernable buttons. This can present a problem for visually impaired persons. Ideally, the control panel should be designed with ridges around each button and some type of tactile identification of button function. If this is not desirable, the manufacturer may make available either a raised letter or braille overlay. These could be available free upon request (order information should then be prominently presented in the product installation and operating instructions).

Compatibility With Assistive Devices:
Sometimes direct accessibility, or even the use of standard options, is impractical for the mass market producer. This is particularly true for individuals with severe impairments (e.g., a person with a severe physical disability may be unable to use a standard keyboard).

There are manufacturers of "assistive devices" providing customized or specialty items to meet the specific needs of individuals with disabilities (e.g., a special keyboard which can be operated by eye gaze). Unfortunately, it is often difficult or impossible to connect the assistive devices to standard products.

Cooperation between mass manufacturers and special manufacturers could result in standard products which facilitate the connection and use of assistive devices.

> *An example.* Many persons with physical disabilities cannot use standard computer keyboards. Some of these persons would require more extensive modifications than would be possible using the first two accessibility approaches discussed. Currently, there are several specialty manufacturers who make alternative input devices to fit persons with a variety of severe physical disabilities. However, the manufacturers of these assistive devices have always had problems ensuring that the devices would work with standard, commercially available computers. As part of the effort by the computer industry to cooperate with manufacturers of assistive devices, Microsoft now distributes an extension to the Windows 3.0™ operating system for IBM and compatible computers called "Serial Keys." This extension allows people to connect alternative input devices to the serial port of the standard personal computer in a way which makes input to the serial port look like it is coming directly from the standard keyboard and mouse. In this fashion the user with a disability can completely access and control the computer and all of its software.

Facilitation of Special Modifications:
There may be some cases where all the other approaches to accessible design prove to be impractical or uneconomical, most likely for persons with combinations of severe disabilities or where there are relatively few individuals with the same problem (e.g., persons who are totally deaf and blind).

In such cases, custom modifications of the product, either by the product manufacturer or a third party, may be the best solution. Standard product manufacturers should facilitate this as much as they can (e.g., leaving room for special attachments or labels, documenting hooks or places to link into hardware or software, publishing information on safe or effective ways to modify products, honoring warrantees for products which have been modified for accessibility but where the modification did not result in the problem).

> *An example.* Car makers are beginning to include accommodations in the design of some vehicles to facilitate the installation of adaptations for users with disabilities.

Conclusion

Recently, the term "Universal Design" has come into greater usage to represent the design of products to be usable by *all* persons, both with and without functional impairments. Universal design incorporates all of the design principles and specifications for the full range of human ability and limitation. In the Design Guidelines, "Accessible Design" is used to describe that component of universal design that focuses on design principles for persons who, because of personal characteristics or environmental conditions, find themselves on the low end of some dimension of performance (e.g., seeing, hearing, reaching, manipulating).

Accessible design is a balancing act. To begin with, it must be acknowledged that it is unreasonable to design *everything* so that it can be used by *everyone* (regardless of their limitations). However, it is equally unreasonable to rely on the existence (or development) of special designs for each major consumer product to accommodate each one of the immense variety of different disabilities (and combinations of disabilities). This makes it necessary to look toward a combination of approaches, ranging from the incorporation of features into consumer products that will make them directly usable (i.e., "from the box") by more persons with disabilities to the inclusion of features that make them easier to modify for accessibility. It is hoped that over time these principles will be incorporated into the general design principles to the extent that "Accessible Design," "Universal Design," and "Standard Design" will all be synonymous.

Acknowledgements

This work has been supported in part by Grant #H133E80021 from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education.

Gregg C. Vanderheiden
Trace R&D Center, S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

13.2

WHO IS A REHABILITATION ENGINEER?

Lawrence H. Trachtman
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department

ABSTRACT

A survey was mailed to the 285 members of RESNA's Rehabilitation Engineering Professional Specialty Group. Of the 184 respondents, only 120 (65 %) "call or consider themselves *rehabilitation engineers*". Most have an engineering degree (88 %), but few are registered Professional Engineers (24 %). Almost 90 % of the rehabilitation engineers work in either service delivery or research and development activities. There is a strong correlation between job function and work setting, over one-half work in either a university or hospital. Salaries are concentrated between $30,000 and $50,000. Rehabilitation engineers report being proficient in a variety of service-related areas. However, less than one-half received any specialized training in the past year. These results suggest less than 185 practicing rehabilitation engineers nationwide. Further, rehabilitation engineers are possibly becoming stereotyped into clinical, service delivery roles with more advanced, higher-paying career opportunities not readily available.

BACKGROUND

Role confusion and rehabilitation engineers' lack of identity is not new (Corthell, 1979; Corthell, 1986; McFarland and Scadden, 1986; Tanenbaum, 1986). The Sixth Institute on Rehabilitation Issues recommended over ten years ago that "the role of the rehabilitation engineer should be defined". A concise but ambiguous definition for the rehabilitation engineer is that of "problem solver" (Foort, 1985). Rehabilitation engineers are often asked to solve so many problems, that Childress (1984) describes more than ten areas of intensive engineering involvement.

The number of practicing rehabilitation engineers is not known. In 1983, Shapcott and Trefler estimated between 30 and 50 rehabilitation engineers active in service delivery. While this number is undoubtedly greater today, low funding levels for disability-related research and training, together with a lack of reimbursement for rehabilitation engineering skills, may be underlying reasons for this shortage (OTA, 1983). These few numbers might not provide rehabilitation engineers deserved credibility. However, in a show of unity, rehabilitation engineers recently approved a set of position statements on qualifications and certifications for their profession (Levine, 1990).

This study's purpose is to describe the current practices of rehabilitation engineers, and to provide needed data for addressing issues critical to this still emerging discipline.

RESEARCH QUESTIONS

1. What is the educational background of rehabilitation engineers?
2. What areas of practice do rehabilitation engineers work in?
3. What is the geographic distribution of rehabilitation engineers?
4. What settings do rehabilitation engineers work in?
5. What is the salary structure for rehabilitation engineers?
6. What technology areas are rehabilitation engineers proficient in?

METHOD

The RESNA Rehabilitation Engineering Professional Specialty Group (RE-PSG) is the only known group of people identifying themselves as rehabilitation engineers. RESNA members can join one PSG at no charge; there are currently 285 people in the RE-PSG.

A draft survey instrument was developed and submitted for approval to the RE-PSG chairman. Most of the questions were objective, requiring only yes/no or checked responses. A few questions called for numerical or written answers. Mailing labels for the 285 RE-PSG members were obtained from RESNA. A cover letter, finalized survey and self-addressed stamped envelop were then sent to each person. They were given one month to return their completed surveys. Respondents were asked to remain anonymous, and there was no follow-up for individuals who did not respond.

RESULTS

A total of 184 surveys were returned (65%). Of the 184 respondents, 120 (65 %) "call or consider themselves *rehabilitation engineers*". Of these 120 self-identified rehabilitation engineers, 106 (88 %) have an engineering degree and 29 (24 %) are registered Professional Engineers. An additional 29 individuals have an engineering degree but do not consider themselves rehabilitation engineers. For the 120 rehabilitation engineers, the breakdown by degree is 5 Associates, 22 Bachelors, 47 Masters, and 41 Doctorates.

[Note - the following results are based on the data set of 120 persons (out of 184) who call or consider themselves rehabilitation engineers. Possible reasons why some people join the RE-PSG but do not consider themselves rehabilitation engineers are included in the discussion.]

As seen in figure 1, a majority of the rehabilitation engineers consider service delivery their primary area of work (52 %), followed by research and development (37 %). When asked about their secondary responsibilities, however, more rehabilitation engineers responded with education and training (28 %) and management and administration (18 %). Forty percent of the rehabilitation engineers have been practicing less than 6 years (figure 2), and 57 % supervise less than three persons.

Figure 3 shows the geographic distribution of the rehabilitation engineers. Based on these responses, more rehabilitation engineering opportunities appear to be available in the midwest with the fewest in the southeast and southwest. Respondents in the "other" category were often from Canada, Great Britain, and Hong Kong.

Figure 4 shows the distribution of rehabilitation engineers by work setting. Over one-half of the rehabilitation engineers work in either a university or hospital. (The survey question considered hospital to be a general or rehabilitation hospital, and university to be a university or university affiliated hospital.) Few are employed in industry. Considering the two primary areas of work, there is strong correlation between setting and job responsibility (figure 5). Many private practioners also report doing service delivery. Salary ranges for the rehabilitation engineers are shown in figure 6. Table 1 compares academic degrees and average salaries.

Figure 7 shows the technology areas in which the rehabilitation engineers consider themselves proficient (multiple selections were allowed). The areas chosen most often include computer access and use, environmental controls, worksite modifications, seating and positioning, and mobility technologies. The areas least selected are electrical stimulation and robotics. A direct relationship exists between the rehabilitation engineers' areas of proficiency and service delivery activities. Finally, over one-half (53 %) of the rehabilitation engineers have received no work-related training in the past year. RESNA courses and workshops were mentioned most often by those who have received training.

DISCUSSION

The question "Who is a rehabilitation engineer?" cannot be answered as simply as who are mechanical engineers or electrical engineers, for example. Perhaps because rehabilitation engineering lacks a traditional curriculum along with an accredited degree, rehabilitation engineers have come to identify themselves, often to their individual liking. Even finding a group of practicing rehabilitation engineers is difficult. Given 285 members of the rehabilitation engineering professional specialty group, only 185 (65 %) may in fact consider themselves to be rehabilitation engineers. Others who join the RE-PSG possibly have an interest in rehabilitation engineering, or may consider themselves biomedical engineers or research engineers because they do not provide direct client services. It is interesting that less than one-quarter of the rehabilitation engineers in this survey are registered Professional Engineers. The majority opinion of RE-PSG members who said that a P.E. license should not be necessary for rehabilitation engineering certification collaborates this result (Levine, 1990).

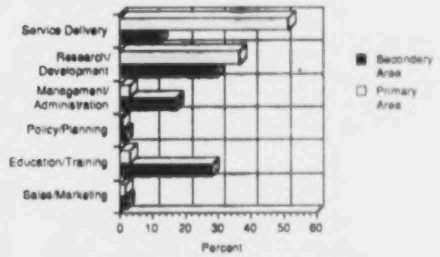


Figure 1. Rehabilitation Engineers' Areas of Work

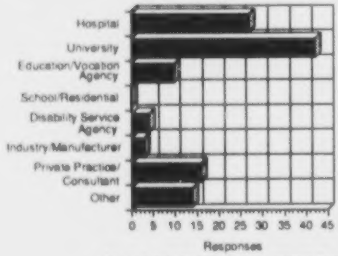


Figure 4. Rehabilitation Engineers' Work Settings

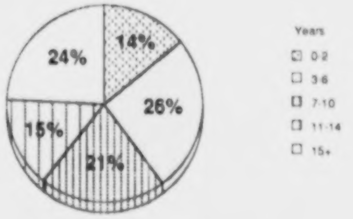


Figure 2. Rehabilitation Engineers' Years Practicing

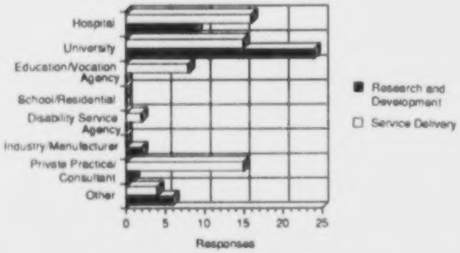


Figure 5. Work Settings for Rehabilitation Engineers doing Service Delivery and Research/Development

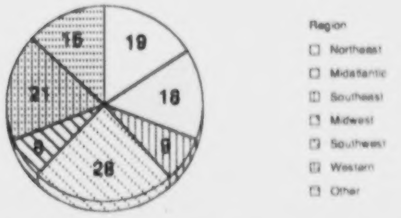


Figure 3. Number of Rehabilitation Engineers by Region

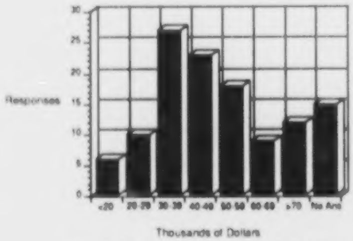


Figure 6. Salary Distribution for Rehabilitation Engineers

Degree	Responses	Average Salary
None	3	$ 33,000
Associates	1	$ 30,000
Bachelors	23	$ 37,600
Masters	44	$ 39,300
Doctorate	30	$ 62,500
Other	2	$ 56,500

Table 1. Rehabilitation Engineers' Average Salaries

Interpreting figures 1 and 2, rehabilitation engineers are possibly becoming stereotyped into primarily service delivery or research and development activities. This notion is supported by a relatively inexperienced work force having few supervisory responsibilities. (Even though the rehabilitation engineers with advanced degrees outnumber those with Bachelors degrees 4 to 1.) While the rehabilitation engineers report education/training and management/administration as secondary areas of work, these more advanced career opportunities (along with policy/planning) do not appear readily available. Taking this one step further, most jobs for rehabilitation engineers still exist in either hospitals or universities. Few of the rehabilitation engineers work in residential settings, industry, or with disability service agencies. Community-based rehabilitation engineering may not be occurring to a large extent, unless rehabilitation engineers go into private practice or consulting. Salaries for rehabilitation engineers are concentrated between $30,000 and $50,000. However, rehabilitation engineers can expect to earn more with a Doctorate degree, especially consulting or in research and development activities.

Rehabilitation engineers report a diversity of proficiency areas covering most types of assistive technologies. Areas least selected are those typically delivered by other professional disciplines; for example prosthetics/orthotics and adaptive recreation. A strong correlation exists between rehabilitation engineering service delivery and self-reported proficiencies. Rehabilitation engineers must be learning their skills on the job since fewer than half received any specialized training in the past year. This should cause concern considering assistive technologies' rapid pace of advancement.

CONCLUSION

Rehabilitation engineering is viewed primarily as a clinical/research service profession, both by rehabilitation engineers themselves and by rehabilitation engineering employers. Few in number, rehabilitation engineers must unify to address critical issues such as training and certification. In addition, the profession must look at career paths which expand potential roles of rehabilitation engineers including opportunities in industry, management/administration, and community-based practices.

ACKNOWLEDGEMENTS

The Center for Rehabilitation Technology Services is part of the South Carolina Vocational Rehabilitation Department and is a rehabilitation engineering center supported by the National Institute on Disability and Rehabilitation Research. Mr. Matthew Ferrante assisted with data entry and analysis; illustrations were prepared by Ms. Valerie Augustine.

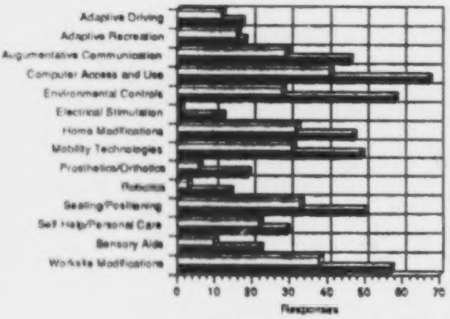


Figure 7. Rehabilitation Engineers' Areas of Proficiency

■ Proficiencies for all Rehabilitation Engineers

☐ Proficiencies for Rehabilitation Engineers doing Service Delivery

REFERENCES

Childress, D.S. (1984). "Rehabilitation Engineering", Mechanical Engineering, 106(9), 56-65.

Corthell, D.W. (1979). Sixth Institute on Rehabilitation Issues, Rehabilitation Engineering: A Counselor's Guide, San Antonio, TX.

Corthell, D.W. (1986). Thirteenth Institute on Rehabilitation Issues, Rehabilitation Technologies, Little Rock, AR.

Foort, J. (1985). "Comments for a New Generation of Rehabilitation Engineers", Journal of Rehabilitation Research and Development, 22(1), 2-8.

Levine, S.P. (1990). "Positions Paper: Certification (Credentialing) of Rehabilitation Engineers", RESNA's 13th Annual Conference, Washington, DC.

McFarland, S.R. and Scadden, L.A. (1986). "Marketing Rehabilitation Engineering", SOMA, 1(2), 19-23.

Office of Technology Assessment. (1983). Technology and Handicapped People, Springer Publishing Company, New York, NY.

Shapcott, N. and Trefler, E. (1983). "The Rehabilitation Technologist and the Rehabilitation Engineer as Vehicles for the Delivery of Appropriate Technology", RESNA's 6th Annual Conference, San Diego, CA.

Tanenbaum, S.J. (1986). Engineering Disability, Public Policy and Compensatory Technology, Temple University Press, Philadelphia, PA.

Lawrence H. Trachtman
Center for Rehabilitation Technology Services
South Carolina Vocational Rehabilitation Department
1410-C Boston Avenue, P.O. Box 15
West Columbia, SC 29171-0015

An Internship Program for the Training of Rehabilitation Technologists

13.3

Susan E. Fridie, MS, OTR
Center for Rehabilitation Technology
Helen Hayes Hospital
West Haverstraw, NY

ABSTRACT

A training program for preparing rehabilitation professionals to specialize in rehabilitation technology is described. The program took the form of a four-month internship at the Helen Hayes Hospital Center for Rehabilitation Technology. Four trainees from different professional backgrounds evaluated three clients with severe disabilities and developed a list of recommended equipment to suit the clients's needs. In addition to work with these clients, the trainees participated in a variety of other learning activities. Based on feedback from trainees and trainers, some basic recommendations for other centers interested in conducting training programs are offerred.

BACKGROUND

Part of the stated mission of the Center for Rehabilitation Technology (CRT) at Helen Hayes Hospital is to facilitate training of health care providers concerning rehabilitation technology. This report describes a project undertaken by the CRT with funding from the Education and Training Foundation of the Paralyzed Veterans of America, Inc. addressing the need for trained personnel to assist disabled consumers in choosing assistive technology which enhances their independent function.

Shortage of trained technologists

Rehabilitation technology (RT) is one of the fastest-changing industries in existence. Most providers of rehabilitation services, with full caseloads, cannot spare the large quantities of time required to become knowledgeable about RT, and especially to *stay current* with the state of the art. Consequently, RT has developed into a specialty: people with clinical or technical backgrounds restrict their activities to RT, becoming what we refer to as rehabilitation technologists.

The demand for RT services is far outstripping the number of specialists available, however. While there are many reasons for this discrepancy, one of the greatest is the difficulty of making the transition from generalist to specialist. As things stand, considerable resourcefulness and a great deal of time and energy is necessary in order to become an RT specialist. Academic programs are scarce. Continuing education offerings abound, but while they may provide introductory material, they can rarely offer enough detail. Further, didactic methods cannot provide the opportunity for practical experience which is necessary to assimilate and apply the principles and techniques learned.

The field is so young that no agreement has yet been reached regarding what kind of training one needs or who should provide it. Discussion in RT circles of all the issues surrounding training is increasing, but it is becoming apparent that these issues are complex and controversial, and will not be easily settled. In the meantime, the shortage of service providers grows more acute.

OBJECTIVE

CRT staff felt that while waiting for consensus on the training and certification of specialists, some action to address the current shortage is appropriate. The Rehabilitation Technology Intern program was designed to

1) encourage a few individuals to become rehabilitation technologists and
2) test a model for RT training, and thereby contribute some data to the broad discussion of training issues.

The Rehabilitation Technology Internship (RTI) program created a team of health professionals to work together in an internship which provided them intensive training in the development and application of rehabilitation technology.

METHOD

The primary training mode was supervised practice in RT evaluation and prescription for three multiply-disabled persons. The interns were responsible, as a group, for the evaluation and eventual selection of equipment for their clients. To accomplish this task with the severely disabled clients assigned to them required close teamwork within the RTI team, and extensive interaction with others inside and outside the hospital.

The training model uses three primary educational modalities:

> Mentorship - The interns worked with CRT personnel of similar professional backgrounds. This is not a teacher/pupil relationship where one person directs the other, but a collegial relationship where one professional, because of specialized knowledge, is in a position to share information and guide another professional through a new experience.
>
> Collaboration - The interns worked with their colleagues on the RTI team and among the CRT staff, with other clinicians involved in the client's care, and with the client/family. Through the collaborative process, the interns learned from one another, learned what they have to offer others, and engaged in group problem solving which expanded the knowledge of all.
>
> Experience - Through observation of and practical experience in evaluating clients, developing appropriate RT systems, and procuring those systems for the clients, under the guidance of experienced mentors, the interns learned the RT service delivery process, and learned it in an integrated fashion that will allow them to apply it appropriately to a wide range of clients in a variety of settings.

The selection of these methods, rather than traditional classroom methods, is based on their appropriateness for the chosen audience. The RTI program trainees are adult professionals, with both a wealth of previous experience and a high level of motivation to learn as much as possible. Motivated adults generally learn best in noncompetitive, self-directed environments, where their existing competence can be capitalized upon. Also, in the absence of established curricula and standards for RT training, traditional techniques such as lesson plans, tests, and grades have little meaning. The program, as designed, carries a powerful mechanism for feedback to the trainees: results. Based on the success of the team in its goal of increasing the independent function of its clients, and comparing this outcome with what they would have been able to produce before the internship, the interns are able to judge the skills they have gained.

Selection of Interns
The internship program was open to all rehabilitation disciplines. Recruitment fliers were distributed through: direct mailing to individuals, rehabilitation centers, and newsletters reaching health professionals; vendors of rehabilitation equipment; workshops and conferences, etc. The most intensive recruiting was done in the northeast, but some coverage was achieved across the country and in Canada.

Most of the approximately 50 requests for further information were from people who were intensely interested in the program, but many of whom were unable to conform to the logistical requirements: they could not get a leave of absence from their jobs, could not manage full-time, or all four months, or the time of year. Many mentioned that they could not manage financially (the stipend of $1,000/month is much less than most professionals earn).

Of these inquirers, eleven people followed through as far a formal application and eight of these were interviewed (two applicants from the Midwest were interviewed by telephone). Selection was based, not on prior experience with technology, but on personal and professional characteristics such as commitment to lifelong learning, willingness to work cooperatively, and a high degree of self-directedness. The overall quality of the applicants was excellent, and making the final choices was difficult.

The interns selected were:
1. a rehabilitation engineering student, who had almost completed her master's degree in biomedical engineering
2. a speech pathologist from a rehabilitation hospital, who has worked primarily with head-injured clients
3. an occupational therapist whose clinical experience has been mostly with pediatric clients, and
4. an occupational therapy assistant, with a background in art, who has worked mostly with developmentally disabled adults.

Selection of Clients
The question of how to recruit clients for the RTI interns to work with was more difficult than it seemed at first. It was considered desirable to find clients whose disabilities would make it difficult for them to achieve their functional goals. It is such clients who stimulate the knowledge, creativity, and resourcefulness of rehabilitation technologists. They also require the most customized, integrated adaptive technology systems--the kind that only a well functioning interdisciplinary team can provide.

However, such challenging clients require enormous amounts of professional time in direct contact, research, fabrication and documentation. If we recruited too widely and identified many such people, those who could not be fit into the internship program would have to be placed on a waiting list until the regular CRT team could see them. At typical CRT clinical loads, such a waiting list could be many months, perhaps a year, long.

Instead, a more conservative, mostly word-of-mouth approach was adopted. The disadvantage to this approach was that only one of the three clients chosen was identified at the beginning of the internship period. The others began later, giving the interns less than the full four months to work with them.

Rather than restrict the program to clients with spinal cord injury, persons from a variety of diagnostic categories were sought. Offering the interns different patterns of abilities and disabilities to work with was intended to produce more rounded training, since it is rare for a rehabilitation technologist to work with only one type of client. Also, coping with such variety encourages a broad, flexible approach which results in better services for all clients.

The clients chosen were:
1. a 26-year-old man with C4-C5 quadriplegia of ten years' duration
2. a 45-year-old woman who received a severe head injury in a automobile accident seven years ago, and
3. a 3.5-year-old boy born with spastic/athetoid cerebral palsy and profound hearing loss.

Internship experience
The interns worked at the CRT for 16 weeks, full time, in March-June of 1990. They received no salary, but did get a stipend to help cover living expenses. Two lived in hospital housing, the other two at home.

The interns evaluated the selected clients with regard to their needs for wheelchair positioning, mobility, augmentative communication, computer access and environmental controls. Assessment of physical capabilities, trials of both commercial and custom-built devices and control mechanisms, home visits and consultation with family members and therapists provided a comprehensive picture of each client's needs. Based on these needs, activities such as trying out equipment, consulting with manufacturers and vendors, obtaining loaner equipment and designing, fabricating, adapting, and refining custom items allowed the interns to compile a list of RT recommendations for each client.

In addition to the intensive work with these three clients, the interns observed the CRT staff work with a variety of other clients, and participated in evaluations and treatment as appropriate. They were introduced to CRT research projects and specialized rehabilitation services at Helen Hayes Hospital. They received more in-depth inservices on various categories of rehabilitation technology devices, and the principles of matching clients' needs to a particular device. They also had the opportunity to design and fabricate simple electrical devices and to work with numerous tools and materials in the fabrication or adaptation of non-electronic adaptive equipment. They took field trips to other rehabilitation technology programs and attended a computer trade show and a wheelchair seating workshop. In addition, several special projects were completed, such as a chart comparing the features of a number of major environmental control systems.

DISCUSSION

The RTI project's planners, when designing the internship exprience, were working without clear guidelines--there were no established criteria for training in this area. Decisions were therefore made on the basis of general educational theory, personal learning styles, departmental experience with rehabilitation technology service delivery, and administrative realities. Some of the original choices also had to be modified based on changes that occurred between the time the program was planned and the time it was implemented. For example, the original plans for the intern team had included a part-time physiatrist. An individual who was completing his physical medicine residency and with a background in engineering was very interested in being part of the program. Unfortunately, he was unable to rearrange his residency year to accommodate the program and no other suitable candidate was available.

At the outset of the training period, the members of the intern team quickly developed an excellent rapport among themselves. In fact, at first, they did *everything* together. Gradually, after acquiring basic knowledge in most areas, their individual interests asserted themselves and they became more differentiated. By the end of the four months, when exit interviews were conducted, there were significant differences in their reactions to several aspects of the program, such as whether or not the educational experience should have been more structured, how valuable the various field trips were, and how much they enjoyed the low-tech versus high-tech adaptive devices.

There were a number of things they agreed on, as well: on the plus side, they learned a *lot* about rehabilitation technology; they feel prepared to keep learning; their initial belief in the need for an interdisciplinary approach to service delivery was strengthened; the hands-on experience with the clients and the technology was the best part of the program. On the other hand: there is *so* much more to learn--it's hard to keep up; they wish they'd seen more clients; and they wish there had been another intern whose focus was on seating and mobility.

The program worked out very well for the clients. Although the combination of the interns, the CRT mentors, the client, and the family members made for a large, and at times unwieldy, treatment team, there's little doubt that being part of the program was a benefit. The clients received high-quality rehabilitation technology services in a more intensive fashion than they would otherwise. They got unusual services, like home visits and equipment loans. One of the interns even talked a salesman at a local computer store into lending her a trackball for one client to try with his mouthstick. Then she guaranteed its return with her personal credit card number!

Recommendations

To draw firm conclusions from one experience with a small group of trainees would be premature. However, the RTI program appears to have been a success in that the interns and the clients all benefitted. In the hope of encouraging other rehabilitation technology centers to undertake training projects of their own, the following recommendations are offered:

First, and most important, is the inclusion of hands-on training. Trainees must get to actually try as much technology as possible--not just briefly, as at an exhibition, but sitting down with a device and the instruction manual and actually making it work. If service delivery is the goal, then trainees must work directly with clients--not just hear case studies or observe others working with clients. For designers and fabricators, opportunities to experience the clinical problem and devise and build a solution are essential.

Next is the efficacy of the team approach. Unless the client's needs are very simple, the necessity for technologists with different subspecialties to combine their pools of knowledge and their points of view is obvious. Whether the team is all trainees, or trainees mixed with other staff, direct experience in a functioning team is essential.

The trainers must be able to devote enough time to the trainees. Virtually every aspect of the RTI program took more time than we anticipated. In the CRT, as in many centers, time is even more scarce than money.

But money is important, too. Significant financial support would seem to be a prerequisite for most trainees. To find a sizeable pool of persons who are willing and able to participate in a lengthy training program with little or no compensation, will take extensive recruiting. However, there may be alternatives to grant funding, such as temporarily filling vacant staff positions, or finding employers who would compensate their staff during training in order to benefit from the skills they gain.

These points are only the highlights. Obviously, there is more to be said, on these and other points, than can be said here. The CRT would be happy to share, in more detail, what we have learned from our experiences with any and all who are interested in the training of rehabilitation technologists.

ACKNOWLEDGEMENTS

Supported by a grant from the Paralyzed Veterans of America Spinal Cord Injury Education and Training Foundation.

Susan E. Fridie, MS, OTR
Education Specialist
Helen Hayes Hospital
Center for Rehabilitation Technology
Route 9W
West Haverstraw, NY 10993
(914) 947-3000, Ext. 3587

13.4

Use of a Database System for Providing Demographic and Outcome Data in an Assistive Technology Clinic

Melissa J. Honsinger, M.A., Elaine Hoglund, M.S., and Walter C. Stolov, M.D.
Assistive Technology Clinic, Department of Rehabilitation Medicine
University of Washington
Seattle, WA

ABSTRACT

Over the past 15 years, as technology development and its use have increased, service providers have been faced with the question of how to meet their clients' needs within their financial constraints. The Assistive Technology Clinic (ATC) began as a means of developing a quality service delivery program for disabled persons with technological needs. As described in DeRuyter and LaFontaine (1987), the use of a database can provide valuable information regarding clinical service delivery patterns and needs. Presently, the ATC is using a database to examine both client demographic and technological needs as well as provide methods to improve the quality of the service care delivery.

BACKGROUND

The Assistive Technology Clinic provides evaluation and training to persons with physical disabilities who may require technology to reduce the level of their disability. Until April of 1990, persons with physical disabilities in the Pacific Northwest who required evaluation of technological needs had few or scattered resources. The Assistive Technology Clinic has consolidated several previously available separate services into one convenient clinic. The Seating Clinic, the Augmentative Communications Center and Rehabilitation Engineering combined their talents with a physiatrist to provide a truly comprehensive clinic. This clinic, housed in the Department of Rehabilitation Medicine, offers evaluation and prescription for wheelchair seating, adaptive equipment for activities of daily living, mobility and augmentative communication needs.

The goal of the Assistive Technology Clinic is to provide assessment of personal technological and equipment needs, in the home and in the community. The team consists of a physiatrist, occupational therapist, physical therapist, speech pathologist, rehabilitation engineer and nursing, social services and prosthetics/orthotics as needed. Evaluations are completed in the clinic and the patients continue to be followed in the clinic to assure that all equipment is properly implemented. In other instances, patients are referred back to their primary care physicians and allied health personnel with full recommendations for implementation and follow-up.

OBJECTIVE

The rapid growth of the Assistive Technology Clinic necessitated refining procedures to ensure timely and accurate referral, evaluation and delivery of client care services. Since its inception in April 1990, the number of active ATC clients averages 46. Referrals come from multiple sources in the community as well as referrals from the Department of Rehabilitation Medicine inpatient and outpatient units, and other clinics within the Medical Center. Community referrals have come from group homes, nursing homes, independent living facilities, and institutions.

This review has three main objectives: 1) to describe organization of program services, 2) to describe the database currently used to collect client information, 3) to describe preliminary demographic data of current clients. For organization of program services, it is necessary to establish and maintain an accurate count of the clients seen by ATC. In addition, a definition of the clients' status is needed to determine the level of involvement with the ATC team. Active status describes those ATC clients currently seen or scheduled to be seen by one or more members of the

ATC team, or those ATC clients whose case is awaiting funding or equipment.

Another goal of our program is to identify the length of time necessary to initiate client contact.and case management which consists of an initial review of the referral records, followed by evaluation of functional needs or deficits, securing approval for funding, ordering and , developing, or fabricating customized components and finally, training.

The third function we chose to develop was a method to measure the outcome of client care service delivery. The outcomes measured include those services which occur after equipment needs are evaluated, equipment plan is approved by a funding source, recommended equipment is delivered to client, and a final client conference takes place. A final panel takes place to identify an appropriate method and time frame for future client care. A letter is sent to the client or caregiver asking if the client has further equipment needs, or questions regarding equipment adaptation or operation. Upon return of the questionnaire, a decision is made by the ATC team as to whether further client appointments or telephone contact is necessary.

METHOD/APPROACH

We review here the database of all patients seen in the Assistive Technology Clinic beginning from April of 1990, to January of 1991. All of the patient assessed and managed through the Assistive Technology Clinic are included included. All clients or caregivers who contact the clinic are asked to complete a specific intake form which contains information about the patient's medical, educational, vocational and avocational background as well as an indication of problems that may need to be addressed. Categories covered include pain complaints, surgical procedures, medications, specialized equipment, respiratory aids, transportation and communication needs. After receiving the intake form the team members of the Assistive Technology Clinic review the intake form and deciding if any further information is needed (e.g., discharge summaries from hospital stays, surgical reports, reports from vocational counselors, guardian approval).

A Macintosh SE computer was used for database storage and information retrieval. The software chosen to develop the database was FileMaker II which is published by Claris Corp. (1988). FileMaker II is a database publishing system that stores, organizes and synthesizes different kinds of data. It also manages and arranges the information for effective visual communication. The information contained in the database is both basic demographic information as well as clinical information (i.e., clinic appointment dates, next panel date, purpose of panel, outcome of initial appointment, recommendations for further referral, next follow-up date).

RESULTS

A total of 90 clients have been seen in the ATC since April 1990. Of the total clients seen, 48 were male and 42 were female. A review of diagnostic categories showed 7 persons with traumatic brain injury, 28 with spinal cord injury, 37 with cerebral palsy, 9 with mental retardation and 9 with diagnoses of one of the following: cerebral vascular accident,muscular dystrophy amyotrophic lateral sclerosis, or multiple sclerosis.

In the age range from 0-19 years, 2 persons were seen, 40 persons were seen in the range from 20-35, 33 persons seen age range 36-50 years, 12 persons in the 51-65 year range and 3 persons were seen in the > 65 year range.

Of the 90 clients seen thus far, 28 were seen for primarily seating issues, 37 for primarily augmentative communication needs and 29 required intervention in both areas.

DISCUSSION

After reviewing the information collected to date, it becomes clear that quality service delivery to this population is a multi-faceted problem. The use of a database is making it possible for the Assistive Technology Clinic to meet this challenge by:

1. More accurately describing its patient population
2. Predict the length of time for equipment implementation based on vendors and/or funding sources
3. Examine allocation of clinical resources for purchase of frequently used evaluation equipment that needs to be kept in stock
4. Begin to examine diagnostic-related seating principles
5. Provide a system for following patient evaluation, equipment prescription and measuring outcome of the process

Future plans for the ATC include development of standardized follow-up letters and phone calls at 6 months and 1 year, as well as a description of how prescribed equipment is being utilized at those same time intervals.

REFERENCES

1. DeRuyter, F., and LaFontaine, L.M. (1987). The Non-speaking Brain Injured:A Clinical and Demographic Database Report Augmentative and Alternative Communication, 3,18-25.

2. FileMaker II (1988). Claris Corp., Mountain View, CA.

Melissa J. Honsinger, M.A., C.C.C.-SP
Clinical Chief
Speech Pathology Services
Department of Rehabilitation Medicine
University of Washington, RJ-30
Seattle, WA 98195

A Survey of Tennessee DRS Employees on Assistive Technology

Stan Cronk, Ph.D.
Rehabilitation Engineering Program
University of Tennessee, Memphis
Memphis, Tennessee 38163

Abstract

During February and March, 1990, a survey was conducted of all counselors and supervisors who work for the Tennessee Division of Rehabilitation Services. (DRS). The purpose of the survey was to gain some understanding of how DRS counselors are providing assistive technology services in Tennessee and what those counselors and their supervisors perceive to be the most important assistive technology services to which they may not have ready access The survey was developed through the participation of all this agency's staff members and reviewed by administrators of DRS. The most significant result of the survey is the length of time that passes between the time that a counselor receives a recommendation for a device for his or her client and the time that the client receives the device (as much as 5½ months for computer systems). Another significant result is the degree of variation among regions for the length of time required to provide devices and the variation in the personnel involved in making decisions for clients, such as who chooses and who installs assistive technology devices.

Background

In an effort to learn about how its field employees (counselors and supervisors) provide assistive technology to their clients and to determine what the field employees perceive as the primary needs for assistive technology in Tennessee, the Tennessee Division of Rehabilitation Services requested that this agency develop and conduct an appropriate survey.

Objective

The purpose of the survey was to gain some understanding of how DRS counselors are providing assistive technology services in Tennessee and what those counselors and their supervisors perceive to be the most important assistive technology services to which they may not have ready access.

Approach

All of the members of the professional staff of this agency participated in the development of the survey, submitting questions relevant to each person's expertise (computer access, augmentative communication, and seating and positioning). After the staff developed and reviewed draft copies of the survey, it was reviewed and approved by the local regional supervisor for DRS and by the Director of Rehabilitation Services of Tennessee. Copies of the survey were mailed to each of the nine regional supervisors in the state. Each copy was identified with the name of the counselor or supervisor who was expected to complete it. A short introduction stating the purpose of the survey and brief instructions for filling out the survey were attached to each copy. A deadline was established for the return of the surveys. After the deadline had passed, additional copies of the survey were mailed to each of the regional supervisors, along with a letter of encouragement asking for complete cooperation in filling out the surveys.

For ease of data entry, a form similar to that of the surveys was developed as a HyperCard stack, so that the individual entering information from the returned copies of the survey could "point-and-click" at the appropriate answer. This information was transferred to a spreadsheet program for analysis.

Results

Twenty-seven out of 33 supervisors and 129 out of 156 counselors (including business enterprise teachers as well as rehabilitation counselors) responded to the survey. The responses from the supervisors were used only for comparison with counselors for the perceived need for assistive technology services.

The counselors report that they carry an average of about 83 clients in their caseloads, though the average in each region varies from 57 to 101. The counselors consider about 56% of their clients to be severely disabled, with the average in each region ranging from 45% to 72%. Generally, the higher the percentage of severely disabled clients in a region, the fewer the number of clients per caseload.

The counselors estimated that about 721 clients could have benefited from using a computer over the last two years, though only about 116 clients (16% of those who could have benefited) received one. About 246 clients received jobs because they could use a computer, however. Counselors are most likely to use their clients for information about determining the kinds of computers that clients should receive, though they frequently use themselves, other counselors, other DRS employees, and other individuals for information about the selection of computer systems. Computer salespersons are most likely to install computer systems for DRS clients, but other consultants and the clients themselves are frequently called on to perform the installation. Generally, about 5½ months pass from the time a recommendation for a computer system has been made before the system arrives.

The counselors estimated that about 289 clients could have benefited from some form of communication other than speech over the last two years, though only 59 clients (20% of those who could have benefited) received one. Generally, about 3 months pass from the time a recommendation for an augmentative communication aid has been made before the aid arrives. Counselors are most likely to employ a speech/language pathologist to train the client how to use an augmentative communication aid, though manufacturers and other individuals are frequently employed, also.

About 96% of DRS clients do not use a wheelchair at all. Of those that do, the most commonly reported problems with the wheelchairs are difficulties with transporting the wheelchair and pressure sores. Counselors indicated that about 157 of their clients would benefit from a wheelchair if cost were not a problem, and about 150 would benefit if transporting the wheelchair were not a problem. Fifty-three counselors (about 79% of the those responding to the question) indicated that their clients are easily able to find repair services. Fifty counselors (39% of those responding to the question) indicate that their clients are required to pay for repairs and maintenance of their wheelchairs, while 43 counselors (34% of those responding to the question) indicate that DRS pays for repairs and maintenance. About 3 months pass from the time a recommendation for a wheelchair has been made before the wheelchair arrives.

Counselors were asked to estimate how many of their clients could benefit from one or more of several types of assistive technology services. The results are summarized in Table 1.

Table 1. Estimated numbers of clients in Tennessee who could benefit from assistive technology services.

Type of technology	Estimated number of clients who could benefit
Van modifications	252
Seating	406
Augmentative Communication	501
Computer Access	608
Mobility	775
Driver Evaluation and Training	815
Adaptive devices for individuals who are hearing impaired	841
Aids for daily living	860
Adaptive devices for individuals who are visually impaired	1,862

Both counselors and supervisors were asked to indicate their level of interest ("highly interested," "somewhat interested," or "not interested") in a number of assistive technology services which might be provided in Tennessee in the near future. The results are summarized in Table 2.

Table 2. Interest of DRS field employees in potential assistive technology services in Tennessee

Service	Overall rank for counselors	Overall rank for supervisors
in-service training for counselors on computer literacy and adaptive computer access hardware and software	1	4
lending library for computers, software, and adaptive equipment so that clients and counselors can "try before they buy"	1	4
training the client how to use a computer and software	3	1
state-wide network for linking counselors and experts on subjects such as adaptive equipment	3	7
workplace/workstation evaluations and modifications to remove architectural barriers to homes or places of employment	5	2
recommendation lists for computers and software or other adaptive equipment for clients who cannot come to Memphis to be evaluated	5	7
liaison for working with client, counselor, and equipment manufacturers, and software vendors when problems with a computer system arise	5	4
Microcomputer Evaluation Laboratories in other parts of TN	5	14
disabled driver evaluation and training	9	12
evaluations for architectural modifications (home and/or work)	9	14
mobile services, in which an engineer and/or OT would travel around in a van to perform evaluations, installations, and repairs	9	7
computer access evaluations at the client's home or place of employment	9	2
set-up and installation of computers and software at the client's home or place of employment	9	7
lending library for ADL aids	14	17
over-the-phone help for solving problems with computer systems	14	7
lending library for augmentative communication aids	16	19
evaluations for van modifications	17	12
evaluations for advanced workstations, including robot arms	17	20
over-the-phone assistance in setting up computers and software	19	17
implementation of van modifications	19	14

Given a set of 12 computer-related services and 8 non-computer related services, supervisors scored each service higher in importance than counselors did. The positions of each service within the rankings show general agreement between the two groups, however. Computer-related services as a whole ranked much higher than non-computer related services. Of the computer-related services, counselors felt that in-service training for DRS staff members and a computer lending library were the most important; supervisors perceived that client training is most important, followed closely by computer access evaluations performed in the client's home and by evaluations for workstation and workplace modifications. Of the non-computer related services, counselors determined that driver evaluation and training and workplace modifications are most important, while the supervisors felt that mobile services were most important, followed closely by driver evaluation and training and by evaluations for van modifications.

Discussion

One of the most striking observations from the results of the survey is the length of time that passes between the counselor obtaining a recommendation for his or her client till the time that the client receives the assistive technology device or system. For example, administrators within Tennessee Division of Rehabilitation Services became highly concerned when they discovered that their clients must wait an average of 5½ months to receive a computer system after a recommendation for that system has been made, recognizing that employers are unlikely to hold a job open for that length of time. As a result, the administrators have been working with staff members to work out methods of decreasing the waiting periods, such as investigating the establishment of a lending library of computers, software, and adaptive devices that can be provided to clients as soon as approval for receiving computer systems has been obtained.

Another striking observation from the results of the survey is the variation between regions in almost all aspects of service provision. The answers to almost every question in the survey showed high degrees of variations in the responses from each region. Of course, it is to be expected that some regions may be stronger than others in providing certain assistive technology services, but all regions should have similar guidelines for details of service provision such as who should train the client how to operate an assistive technology device. Also, it would seem that if each region has the same requirements for paperwork, then the delay between the recommendation and the installation of adaptive systems should be about the same in each region.

Acknowledgments

This work was supported by a contract with the Tennessee Division of Rehabilitation Services.

Stan Cronk
Rehabilitation Engineering Program
University of Tennessee, Memphis
682 Court St.
Memphis, TN 38163

13.6

PRT - A MASS TRANSIT SYSTEM WITH SIGNIFICANT BENEFITS FOR THE DISABLED AND ELDERLY

Robert Patterson
University of Minnesota
Minneapolis, MN 55455

ABSTRACT

Current or proposed mass transit systems using busses or light rail augmented with paratransit vehicles do not adequately meet the needs of people with disabilities. A new type of personal rapid transit (PRT) that uses small 2 to 4 person vehicles on fixed guideways. It offers the possibility of on demand 24 hour service and point to point travel without transfers. The user would enter the desired destination and vehicle would then travel non-stop to the location. Lobbying for this approach could significantly improve the long term outlook for urban transportation for people with disabilities and the elderly.

BACKGROUND

Serious transportation problems exist for people with disabilities who lack access to an automobile. The Americans with Disabilities Act has addressed the access issue by requiring lifts for public transit vehicles like busses and trains. For individuals who can not use the fixed route transit because of the lack of ability to get to remotely located transit stops, deal with multiple transfers, or the lack of service to the needed destination, paratransit vehicles have been offered as an alternative. Paratransit uses small busses or vans to provide door to door service on a prearranged basis. This relatively expensive service still has many obstacles for people with disabilities. The following is an example of the type of problems with paratransit service (1).

1. service may require days in advance scheduling.
2. the purpose for a trip may have limits (e.g. doctor or work)
3. the operating hours are limited.
4. cumbersome registration procedure for acceptance.
5. lengthy waiting lists.
6. geographical limitations (e. g. boarder of the town).
7. higher fee than regular bus
8. limited number of rides per month allowed.
9. may not be possible to use with able-bodied frienc
10. lengthy travel times.

Currently operating or planned mass transit systems may offer vehicle accessibility but this does not solve many of the transportation problems of people with disabilities. If travelling requires many transfers and operates only during a limited time period, practical transportation will not be available for people without an automobile.

STATEMENT OF PROBLEM

There needs to be mass transit systems for use by both the disabled and able-boded that can provide point to point service on demand, 24 hours a day operation, and have easy access for people with disabilities. The service should require no vehicle transfers and be not limited to trips between or radially out from city centers.

APPROACH

A new type of personal rapid transit (PRT) has been developed that uses small vehicles (2 to 4 people) running on fixed guideways requiring only 3 feet of space. Stations con be placed near or in large commercial or industrial buildings as well on numerous street locations. The vehicles would be computer controlled with easy access by people with disabilities and available 24 hours a day. The user would enter the vehicle with only friends or family and give the desired destination. The vehicle would then travel non-stop to the programmed destination.

The station loading and unloading would be off the main line. This allows non-stop travel to a destination for all vehicles but most importantly for the disabled and elderly population it permits the frequently needed extra boarding time. For shopping centers, large employers, and large living centers this could be door to door with no outside travel. This is specially important in regions with cold and snowy weather.

IMPLICATIONS

These PRT systems will allow private point to point travel in small computer controlled vehicles without transferring and giving "on demand" service. This concept can revolutionize metropolitan transit for people with disabilities. PRT will benefit everyone, but will have a very significant impact on the lives of people with disabilities. Problems like moving between vehicles at transfer points and waiting for service is a hassle for the able-boded but a much great effort is required for many people with disabilities and the elderly.

DISCUSSION

Adopting PRT systems could result in a change similar to what happened with the personal computer (PC). PCs helped everyone but provided significant communication and educational benefits to people with disabilities.

On April 24, 1990 the Regional Transit Authority of Chicago announced a one year plan to evaluate PRT systems for possible use in the Chicago area. Two companies, TAXI 2000 in Revere, MA and Cabintaxi in Detroit, MI, have designs for PRT system. TAXI 2000 has shown detailed designs that cover vehicles, guideways, networks, control, accessible stations and user safety.

Bondada and Neumann surveyed 120 transportation professionals asking a number of questions comparing PRT with numerous other forms of mass transportation. In the area of comfort, convenient, travel times and service to the handicapped and elderly, PRT was the most preferred technology.

I believe the community of people with disabilities and the elderly should lobby on both at the national and local level for governments to consider PRT systems for urban mass transit.

REFERENCES

1. Overview of The Americans with Disabilities Act of 1989. President's Committee on Employment for People with Disabilities. 1989 mailing.
2. Bondada M, Neumann E. Perceptions of PRT Among Transportation Professionals. J. of Adv. Transportation 23:1-18, 1989.

Robert Patterson, Ph.D.
Associate Professor
University of Minnesota Hospital
UMHC Box 297
Minneapolis, MN 55455

14.1 Using A Social Approach in the Development of a Communication Aid to Achieve Perceived Communicative Competence

Andrew McKinlay
The Microcomputer Centre
The University of Dundee
Dundee DD1 4HN
Scotland, U.K.

ABSTRACT

This paper sets out a novel distinction between "technical" and "social" approaches to the design of communication aids. It then describes a communication system called MOSCO which was designed in accordance with the "social" approach. The system is designed to allow the user a high level of perceived communicative competence. It works by using conversation analytic techniques to generate predictions about which phrases the user could employ within the current conversational context.

BACKGROUND

Traditional, "technical" approaches to communication aid design concentrate on the difficulties associated with refining models for text generation, improving word output rate, extending voice characteristics and so on. But recent years have seen a call for a broad view of communication in the discussion of communication aids (Light, 1989; Zangari, Kangas & Lloyd, 1988). In particular, it has been suggested that a future area of concern should be the social psychological concomitants to communication, including perception of self by others (Calculator, 1988; Kraat, 1985). This suggests the possibility of an alternative approach to communication aid design which would take the non-speakers' social difficulties as a starting point: a "social" approach.

For example, a major social psychological problem for the communication aid user is that when others perceive the user's lack of communicative competence, they may mistakenly attribute undesirable psychological characteristics such as lack of intelligence or low social skills (Zebrowitz, 1990). A "technical" approach to this problem would begin with a text generation model and work toward improvements in perceived communicative competence. A "social" approach, on the other hand, would begin with a model of perceived communicative competence and then work back to a text generation model.

THE PROBLEM

On the basis of this distinction between "technical" and "social" approaches, it was decided to develop a communication system - MOSCO (MOdular SOcial COmmunicator) - using the "social" approach. It was intended that the system would be specifically designed to enhance the user's perceived communicative competence in conversation.

There are at least 3 criteria involved in attaining, by means of a communication aid, perceived communicative competence within a conversation.

(i) The rate of verbal output should normally be relatively high.

(ii) The output should normally be made up of relatively small language units. (Typically, each speaker will contribute only a few phrases to a conversation before allowing another to speak.)

(iii) The content of each language unit should be, to a greater or lesser extent, context-dependent. (Each conversant's contributions will usually be determined by, or at least perceived as relevant to, the overall conversational context.)

So the goal set for MOSCO was to generate short, context-dependent language units relatively quickly.

DESIGN

In operation, MOSCO allows the user to create phrases on a word-processor device and "speak" these via a voice synthesizer. As each phrase is generated, the system performs a syntactic analysis upon it and then stores its analysed form in a "conversational diary" along with all other previously uttered phrases. The system then searches this "diary" for a number of suitable successor phrases.

This search is guided by a form of semantic analysis. Employing methods derived from work in conversation analysis (Atkinson & Heritage, 1984; Brown & Yule, 1983) MOSCO uses the latest input phrase to formulate a representation of the current conversational topic. This is then used to guide its search through the "diary" of previously uttered phrases. This ensures that the list of successor phrases which MOSCO selects includes only sentences which have been uttered within the same conversational topic in the past.

These successor phrases are then presented to the user as a list, any member of which the user can "speak" by means of a single input (keystroke, mouse button-click, switch selection etc.) as an alternative to creating a new phrase.

By operating at the phrase level, MOSCO meets the first two criteria noted above. It generates text at a relatively high rate even though the text units may be as small as single phrases. It also meets the third criterion: context-dependence. Because the phrases which are offered have occurred within the same conversational topic in the past, this guarantees that each of the offered phrases can be perceived as relevant to the current conversational context.

So by allowing conversational contributions which are of the appropriate length, speed and content matter, MOSCO represents a system which can provide a high level of perceived communicative competence for the user.

EVALUATION

The system is currently being evaluated across a variety of experimental settings. Co-conversants and third party observers are asked to examine transcript of tape-recordings of conversations which involved the use of MOSCO. They are asked to provide estimates of the communicative competence of the user, based on his/her conversational contribution. These estimates are compared with results from a control condition in which transcripts of conversations among normal communicators are presented.

DISCUSSION

In addition to providing a means of achieving perceived communicative competence, MOSCO may prove influential in the design of other text-generation systems. Recent work in AAC aid design demonstrates the importance of working at the sentence or phrase level, rather than the word level (Sy & Deller, 1989). At the same time, recent findings in computational linguistics suggest that a proper analysis of sentences requires that they be considered in relation to the larger body of discourse in which they appear (Seuren, 1985). MOSCO represents an early attempt to apply this to conversational discourse.

REFERENCES

Atkinson, J.M. & Heritage, J. *Structures of Social Action*, Cambridge: Cambridge University Press, (1984).
Brown, G. & Yule, G. *Discourse Analysis*, Cambridge: Cambridge University Press, (1983).
Calculator, S.N., Evaluating the Effectiveness of AAC Programs for Persons with Severe Handicaps, *AAC*, 4, 3, (1988), pp. 177-179.
Kraat, A.W., Communication Interaction Between Aided and Natural Speakers, Toronto: *Canadian Rehabilitation Council for the Disabled*, (1985).
Light, J., Toward a Definition of Communicative Competence for Individuals Using Augmentative and Alternative Communication Systems, *AAC*, 5, 2, (1989), pp. 137-144.
Seuren, P.A.M., *Discourse Semantics*, Oxford: Basil Blackwell, (1985).
Sy, K.S. & Deller, J.R. Jr., An AI-Based Communication System for Motor and Speech Disabled Persons: Design Methodology and Prototype Testing, *IEEE Transactions on Biomedical Engineering*, 36, 5, (1989), pp. 565-571.
Zangari, C., Kangas, K.A. & Lloyd, L.L., Augmentative and Alternative Communication: a Field in Transition, *AAC*, 4, 2, (1988), pp. 60-65.
Zebrowitz, L.A., *Social Perception*, Milton Keynes: Open University Press, (1990).

ACKNOWLEDGEMENTS

This work was supported by The Spastics Society.

ADDRESS

Andrew McKinlay
The Microcomputer Centre
Department of Mathematics and Computer Science
University of Dundee
Dundee DD1 4HN
Scotland
U.K.

ENHANCEMENTS TO THE SEMANTIC COMPACTION PARADIGM FOR VOCABULARY ORGANIZATION

Clifford A. Kushler, Ph.D.
Prentke Romich Co., Wooster, Ohio

ABSTRACT

The semantic compaction paradigm for vocabulary organization has been widely used in the field for a number of years and has been clinically found to be very useful for a wide range of clients. Three new enhancements to the semantic compaction paradigm are described which have been implemented in a prototype software simulation.

BACKGROUND

The semantic compaction paradigm for vocabulary organization has become widely known in the field of AAC. Since its introduction by Baker in 1982 [Baker Patent No. 4,661,916], it has seen widespread clinical application as embodied in the Minspeak™ operating system software in the Touch Talker™, Light Talker™ and IntroTalker™ devices. Semantic compaction represents language using multimeaning sequenced icons. Language items thus represented can be stored and retrieved electronically through actuating keys or other means bearing multimeaning indicia [Baker, 1982]. The operational features of the Minspeak™ system have remained basically unchanged since its introduction in the Touch Talker™ in 1984, although a revised version has been developed and will soon be released which includes certain enhancements such as improved editing features. Numerous clinical studies have shown it to be a highly effective method of vocabulary organization for a wide range of clients, from very low functioning to very high functioning, using a variety of selection techniques and base vocabularies [Vanderheiden and Lloyd, 1986]. One trend which has become predominant in recent years is the use of professionally designed vocabulary packages, Minspeak™ Application Programs, or MAPs™ [Bruno, 1989].

STATEMENT OF THE PROBLEM

The widespread usage of the Minspeak™ system has provided many opportunities to discover ways in which the system might be improved. While MAPs™ have been designed using icon sequences based on consistent paradigms and rationales in order to be easily learned and fluently used, it is only to be expected that the large amount of vocabulary included in a MAP™ makes this a considerable learning task. Another result of the large vocabulary included in MAPs™ is the correspondingly large amount of memory required for its storage. This has sometimes been seen to result in a shortage of memory for the client's customized vocabulary. Another need (which is by no means unique to Minspeak™) is to improve the efficiency of the selection technique used to access the system. This is especially true for selection techniques based on some form of scanning.

A third opportunity for improvement lies in the realm of keystroke efficiency in text generation using Minspeak™. One study has shown that text generation using the Words Strategy™ MAP™ can result in an average keystroke savings per word of more than 60% for text samples drawn only from words included in the MAP's™ vocabulary [Higginbotham, In Press]. However, Minspeak™ is inherently a multi-modal system, in which the same keys on the keyboard can designate either a single character (in Spell mode) to generate words not in the vocabulary, or a single icon, which can be sequenced to retrieve an item stored in the vocabulary (in what is refered to as Icon mode in this paper). This requires two extra keystrokes each time the mode must be switched to spell a word (one to activate Spell mode, and another to re-activate Icon mode). This additional penalty was shown to reduce the overall keystroke efficiency from more than 60% to 37% in the same study.

APPROACH

The enhancements to the Minspeak™ technique described in this paper are the result of the combined experience and insights of a number of people listed in the Acknowledgements. They have been implemented as a software simulation of a Minspeak™-based AAC system using a prototype keyboard which consists of an 8 x 16 key matrix with a software controlled LED associated with each key. Predictive scanning and automatic mode selection have patent pending status from two separate applications.

Icon Prediction and Predictive Scanning. Regardless of an individual's familiarity with the principles of semantic compaction, or even a knowledge of many of the commonly used associations for the icons used in a particular MAP™, the large amount of vocabulary involved requires a significant amount of exposure and study to become "fluent" in its use. This is only to be expected, since a MAP™ may contain thousands of items stored under various icon sequences. Any guidance that could be provided in learning a MAP™ or in recalling seldom used words in an otherwise familiar MAP™ would be of potentially great benefit. Virtually everyone who begins to "explore" an unfamiliar MAP™ will try to make logical guesses as to the icon sequence under which a particular target item might be stored, based on the understanding of the underlying rationale and semantic associations with each icon used in the MAP™. Even though the choice of an icon sequence for an item is based on a logical and self-consistent rationale, it is by no means deterministic, since each icon is rich in associations and a logical case may be made for more than one choice of an icon sequence. Thus, providing some form of guidance to supplement the user's intuition would significantly help a person's understanding of the underlying rationale of a MAP™ to grow with its continued use.

Let us define a "valid" icon sequence as a non-empty sequence (under which an item has been stored) or a prefix which can be continued to complete a non-empty sequence. It was realized that an LED matrix on the front panel of a device could be used to provide feedback regarding which icons were valid at each point in entering a sequence. Before beginning to enter a sequence, the LEDs would light up at every location corresponding to an icon which occurs as the first icon in at least one non-empty sequence. As subsequent icons are selected, the LEDs would be lit only at those locations corresponding to icons which are valid successors of the previously selected icons. The prototype keyboard described above was constructed so that icon prediction could also be used in systems using a touch panel for direct selection.

A further and very significant benefit can be gained in applying this technique to systems using some form of scanning as the selection technique of choice. By taking advantage of icon prediction, it is possible to speed up the scanning process greatly by only scanning through locations corresponding to valid icons. With most large MAPs™, there is little noticeable change in scanning to choose the first icon in a sequence, since virtually all icons are used to begin at least one sequence and are therefore valid. However, the number of locations to be scanned when choosing the second (and subsequent) icons is almost always drastically reduced, making it possible to scan to the desired location in a fraction of the time that might otherwise be required.

Automatic Mode Selection. As was noted above, the keystroke efficiency of the semantic compaction paradigm in large-corpus text generation tasks can be impaired by the need to activate designated keys to change between Spelling and Icon modes. A method has been devised can can virtually eliminate the need to activate designated mode-switching keys, especially when used with a MAP™ which has been designed using a rationale which takes into consideration the use of this method. The method is based on the assumption that the system operator will not knowingly select an icon which does not form a valid sequence. In the context of a system which provides icon prediction feedback as described above, this is certainly a reasonable assumption. The system defaults to being in Icon mode. When an icon is selected which does not form a valid sequence, and each of the preceding icons in the sequence up to that point resulted from the activation of locations which correspond to valid characters in Spelling mode, it is assumed that the operator was in fact intending to spell a word rather than activate an icon sequence. At that point, each of the preceding key activations is automatically re-interpreted (by the system) as if Spelling mode had been active, and the corresponding characters are generated and sent to the system display. The system switches to Spelling mode, and remains in Spelling mode until a word delimiter (such as the space character) is entered, at which time the system automatically reverts to Icon mode. In this way, the need to activate designated mode-switching keys can be completely eliminated.

One constraint is required in order to use automatic mode switching in a maximally efficient manner. The MAP™ which is used should avoid using icon sequences in which all of the icons are located on keys which also correspond to spelling characters, at least when the order of the icons in the sequence corresponds to a sequence of characters which occurs in English words. While this may seem to be a limiting constraint, in fact it is not. Although the Words Strategy™ MAP™ was designed prior to the conception and formulation of the automatic mode switching method, it contains only a handful of sequences (out of more than two thousand) which would need to be revised in order to avoid any possible conflict.

Another consideration which must be taken into account is whether this system would make it potentially more difficult for the system operator to recover from an unintended key activation. With automatic mode switching, an unintended key activation can result in both a mode switch and the generation of text (spelling characters from the previous icon activations). Given that some system operators may produce a relatively high number of unintentional key activations, it would be a serious disadvantage if the user had to both change modes and delete the generated text. However, it is possible to design an "Undo" function key, which allows the user to completely restore the state of the system prior to the unintended key activation. It is also possible to have the Undo function serve to take care of the situation where the system operator has chosen to store personalized vocabulary under a sequence which corresponds to a valid English spelling sequence. This could result in recalling the personalized vocabulary item when actually trying to spell a word (thus, all of the keys activated were "intended", but the recall of a stored item was not). In this case, the same Undo function would delete the recalled text, and re-interpret the entire sequence entered in Spelling mode. Thus, error recovery in the automatic mode switching method in the same as in a static mode method - only a single keystroke is required to completely recover from any unintended key activation.

"Dependent" Icons. This is a feature which is designed to enhance the operation of MAPs™ such as Words Strategy™ which include sets of closely related icons such as the grammatical labels NOUN, NOUN PL., A+NOUN, THE+NOUN, and THE+NOUN PL. This enhancement provides two benefits: it reduces the amount of memory required to store the MAP's™ vocabulary, and it simplifies the addition of new vocabulary by the system operator which adheres to the icon sequence selection paradigm of the MAP™. As an example, consider the word "part" which is stored under the sequence SHAKESPEARE - NOUN. In current systems, the other possible forms ("parts", "a part", "the part", and "the parts") must all be stored under their respective sequences, requiring additional storage space amounting to almost five times that required for the single word "part". Furthermore, suppose the system operator wanted to add the word "piece" to the vocabulary. In order to be consistent with the overall scheme of the MAP™, it would also be necessary to separately store the words "pieces", "a piece", etc. under their respective sequences.

This situation can be significantly improved making designating NOUN PL., A+NOUN, THE+NOUN, and THE+NOUN PL. as dependent icons, each of which "depends" on the icon NOUN. A dependent icon functions as follows (we will take SHAKESPEARE - THE+NOUN PL. as an example): When the dependent icon is activated, the vocabulary data base is first searched to see if there is in fact an item stored under that sequence. If so, it is simply retrieved in the usual fashion. This enables the system to handle words which may have irregular forms (e.g. mouse - mice). If no entry is found (as would be the case with "part"), the dependent icon THE+NOUN PL. is replaced with the icon NOUN upon which it depends, and the vocabulary data base is again searched, this time coming up with the singular form "part " (words are stored with a following space). Each dependent icon is also associated with a simple series of editing rules. In this case the rules would be: type the word "the ", then insert the retrieved text "part ", delete the final space and add the letter 's' and a following space. It would be easy to add some conditional editing operations to handle rule-following "exceptions" such as copy/copies and glass/glasses, so that only truly irregular forms such as "mice" would need to be explicitly stored.

Now when the system operator adds the word "piece" to the vocabulary under a sequence ending with NOUN, all of the other corresponding forms are available under their respective sequences. The same approach would work for the group ADJECT., ADJECT+ER, and ADJECT.+EST and for VERB, VERB+S, VERB+ED, VERB+ING, VERB+EN, and TO+VERB.

IMPLICATIONS

The enhancements to the semantic compaction paradigm described in this paper have the potential to significantly increase its efficiency in a variety of ways across a wide range of applications. Although not yet clinically tested in the field, the experience of a number of different individuals has shown a great potential for Icon Prediction to aid a cognitively intact individual in becoming familiar with the use of a large vocabulary MAP™. It seems reasonable to hope that similar benefits will be found for individuals functioning at lower cognitive levels, as long as they are able to grasp the fundamental concept that icons with LEDs that are lit lead to the production of spoken output, while unlit icons do not.

Predictive scanning has already been seen to result in greatly reduced average access times required to recall a completed icon sequence. As mentioned above, there is generally only a negligible improvement in selecting the first icon of a sequence, but a very large improvement when selecting subsequent icons from the greatly reduced set of icons which are valid in the context of the sequence being entered. Various forms of scanning are among the most widely used selection techniques due to their adaptability for persons with very limited motor skills. This promises to provide a significant increase in access speed for a large segment of the population.

Automatic mode switching also has yet to undergo clinical field trials, but again the experience of a number of cognitively intact individuals has shown that there is no inherent difficulty in doing away with the Spell Mode/Icon Mode keys. With only a short exposure, the automatic mode switching is neither distracting nor disconcerting, but can be used quite naturally and smoothly. The potential increase in keystroke efficiency for large corpus text generation has been noted above.

DISCUSSION

The automatic mode switching described above could be further enhanced by including word prediction as a mode which would also be simultaneously active with both Spelling mode and Icon mode (as long as the icons which have been activated also correspond to valid spelling characters). This would only require that a number of dedicated keys be included on the system keyboard to be used in selecting candidate words from the word prediction window. A further advantage of such a system could be gleaned from the fact that common words that are easily retrieved from known icon sequences could be eliminated from the word prediction system, allowing it to display only relatively unusual words and rendering a larger and more varied vocabulary more easily accessible.

Predictive scanning can also be easily adapted to enable the simultaneous use of automatic mode switching. This could be achieved by first scanning a selected row only for currently valid icons (while still in Icon mode). If no selection is made, the row would be scanned again, this time scanning both valid icons and locations with spelling characters. This would yield all the benefits of Predictive scanning, while imposing only a minor time penalty when automatically switching modes.

Other investigations are also being carried out to determine whether icon prediction may also be used to increase the efficiency of direct selection techniques (such as optical headpointing) by temporarily expanding the apparent size of isolated valid targets with no immediately neighboring valid icons.

ACKNOWLEDGMENTS

I would like to acknowledge that these enhancements are the result of the collaborative efforts of a number of different people. Predictive scanning and automatic mode selection were initiated at Semantic Compaction Systems. The "Dependent icon" technique was initiated at the Prentke Romich Company. All three of these systems represent collaborative efforts of the Prentke Romich Company and Semantic Compaction Systems. The team includes: Bruce Baker, Clifford Kushler, Edward Gasser, David Hershberger, Jeffrey Higginbotham, Donald Spaeth, Robert Conti, Barry Romich, Brian Yoder, and Eric Nyberg.

REFERENCES

Baker, B. (1982). Minspeak, *Byte*, September, 7, 9, 186-202.

Bruno, J. (1989). Customizing a Minspeak™ System for a Preliterate Child: A Case Example, *Augmentative and Alternative Communication* (AAC), 5, 2, 88-100.

Higginbotham, J. (1990). Stockholm, Sweden, International Society for Augmentative and Alternative Communication Presentation, (In Press).

Vanderheiden, G. & Lloyd, L. (1986). Communication Systems and Their Components, In S.W. Blackstone Editor, *Augmentative Communication:An Introduction.* Rockville, Maryland: American Speech-Language-Hearing Assocation.

Clifford A. Kushler, Ph.D.
Technical Director, Prentke Romich Co.
1022 Heyl Rd., Wooster, OH 44691

14.3

The Design of a Device Independent Screen Class for Augmentative Communication Software

Patrick Demasco, J. Eugene Ball, John Dunaway, William Bradley
Applied Science and Engineering Laboratories
University of Delaware/Alfred I. duPont Institute
Wilmington, Delaware USA

Abstract

The development of computer-based Augmentative Communication systems can be facilitated by the use of an AAC software toolkit. We have worked towards that goal by the development of a C++ based software library called LASO. In this paper we discuss the design of the software component that implements a graphics display interface and present a design that is portable across different hardware platforms. In addition, we discuss a specific implementation that provides an interface to the X Window environment and to the Curses screen interface library.

Background

The evolution of microprocessor technology has provided the AAC developer with opportunities to create increasingly sophisticated systems. Functions such as rate enhancement (e.g., word prediction) and dynamic presentation of symbol-based vocabulary sets are now possible because AAC hardware can support the required processing speeds and memory requirements. With this increasing software sophistication (and complexity) comes an added burden to the software developer. The goal of the Software Architecture project currently underway at Applied Science and Engineering Laboratories (ASEL) is to investigate methods to facilitate more expedient development of complex AAC software systems. Our approach has been to design and develop an AAC software component library that could be used by other system developers (Demasco, Ball, and Kerly, 1989). This work is an extension of earlier efforts by Hugh MacMillan Rehabilitation Center in the area of computer access (McDougal, Knysh, Devkumar, Shein, and Lee, 1988).

LASO, which stands for Library of Adaptable Software Objects, is a software under development at ASEL (Demasco, Ball, and Kerly,1990). It consists of a collection of C++ class hierarchies that implement functional AAC software components. Classes currently under development include: Vocabulary Set, Input and Output Device, Text Editor, Word Predictor, Abbreviation Expansion, and Word Morphology. High level program logic and object connections are accomplished through an interpretive authoring language called *Adapt* which is based on LOGO (Ball, and Demasco,1990).

Statement of the Problem

One of our major design goals is to allow the use of LASO on a variety of hardware platforms. To accomplish this, it is necessary to make most classes hardware independent and to isolate necessary hardware dependencies into a small number of classes. The interface to the system's graphics display is particularly challenging in this regard. A wide variety of display hardware and graphics environments (e.g., windowing systems) currently exist. While there are many similarities between systems, there is also a large number of differences in how windows and graphics operations (e.g., drawing) are implemented.

Our initial implementation of LASO was based on Sun Workstations running the Sunview windowing system. The Sun environment is ideal for exploration of ideas, but at this point is not practical for development of end user systems. In working towards more practical platforms (e.g., laptop MS-DOS PCs running Microsoft Windows) we needed to redesign the screen interface to be system independent.

Approach

Our general approach in the design of C++ class hierarchies that implement device dependent features is to define an abstract base class that defines a generic interface and provides device independent functionality. Specific hardware devices are then implemented as derived classes that implement device specific behaviors. This approach was successful in the development of an input/output device class (Demasco et. al., 1990). We have continued to use this approach in the design of a Screen class hierarchy.

Screen Model

An instance of class Screen is roughly equivalent to a window (multiple windows are not yet supported). Once a Screen is instantiated, a number of graphics operations are available to the programmer. These include drawing text with support for multiple fonts and graphics images (called PixShapes). Drawing operations can specify background and foreground colors. All drawing operations are done to a hidden buffer that is quickly displayed on the physical screen with a showFrame operation.

Screen Class Hierarchy

The class diagram for the Screen class is shown in Figure 1. It consists of an abstract base class called scr_base and derived classes that implement interfaces to specific screen environments.

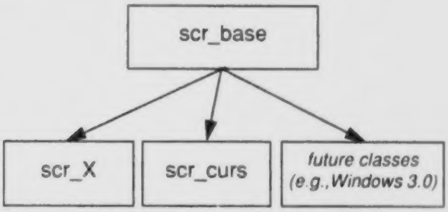


Figure 1. Screen Class Hierarchy

Currently, two screen environments that operate on Sun workstations are supported: X Windows which itself is a hardware independent windowing system (currently limited to the Unix operating system) and Curses which is a text based screen interface package that runs under Unix but is available for other operating systems including MS-DOS. These environments are implemented in the scr_X and scr_curs classes.

Class Methods - In our design, we have tried to limit the number of graphics functions to those that are most important for AAC software. This decision was based on facilitating software portability and minimizing complexity for programmers that will use the Screen class. We anticipate that in the future we may add class methods that support additional graphics primitives. The major class methods include:

init(int xpos, int ypos, int width, int height, LColor fg, LColor* bg):* This method creates a window on the display of specified size (width, height) at a specified location (xpos,ypos). It sets the default foreground and background colors (fg,bg).

*placeText(int xpos, int ypos, char *str, LFont* fnt, LColor* fg, LColor* bg):* This method places a text string (str) at the specified location (xpos,ypos) with the specified drawing attributes (fnt,fg,bg).

textSize(char str, LFont* fnt, int &habove, int &hbelow, int &width):* This method returns the size of text string (str) for a specified font (fnt). The values returned specify the height above the baseline (habove), the height below the baseline (hbelow), and the width of the string (width).

*placePixShape(int xpos, int ypos, LPixshape *image, Lcolor * fg, LColor* bg):* This method places a graphics image (image) at the specified location (xpos,ypos) with the specified drawing colors(fg,bg).

placeRect(int xpos, int ypos, int width, int height, LColor fg, LColor* bg, enum borderstyle bdr)*: This method places a rectangle of specified size (width,height) at a specified location (xpos,ypos). It draws the rectangle with the specified colors (fg,bg) and with a specified border style (bdr).

placeLine(int xstart, int ystart, int xfinish, int yfinish, LColor fg, LColor *bg, enum linestyle ln)*: This method draws a line from the specified start position (xstart, ystart) to the specified finish position (xfinish,yfinish). It draws the line with the specified colors (fg,bg) and with a specified line style (ln).

startFrame(): This method clears the hidden image buffer and prepares for subsequent drawing operations.

showFrame(): This method quickly transfers the hidden buffer to the physical display.

Support Classes

In addition to the Screen Class hierarchy there are a number of aspects of our design that are best implemented with a separate set of support classes. These include the major graphics resource colors, fonts, and images. We have chosen a model based on the Interviews C++ graphical interface toolkit (Linton, Calder, and Vlissides, 1988). In their model each graphics resource type exists as a class that is derived from an abstract Resource class. In our design, shown in Figure 2., colors (LColor), fonts (LFonts), and PixShapes (LPixShape) are derived from LResource.

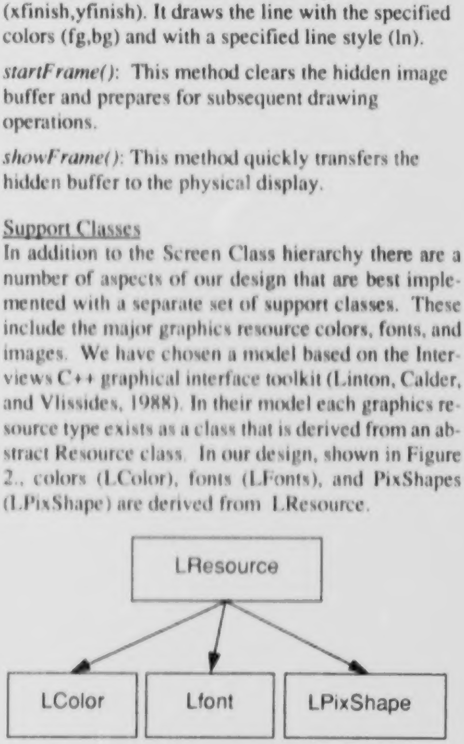


Figure 2. Resource Class Hierarchy

The abstract class provides a uniform hardware independent way for applications to request resources. One key element of this strategy is that each Screen class must define a set of logical resources that are available to applications. This includes a font called "system" and two colors called "foreground" and "background". In this way applications that use only predefined resources can be ported between different screen environments without changes to source code.

Colors and Fonts - The current implementation of LColor and LFont are relatively simple in that they generally request resources from the defined Screen class. The LResource class then maintains tables of available resources. If an application requests a resource, the resource table is first checked, and if it is not found, the LResource class issues a request to the

Screen class. Resources are requested by an application through a constructor statement. An LFont constructor would be of the form:

```
LFont* Fsystem = new Lfont(Screen, "system");
```

where Screen is a globally defined pointer to an instance of a Screen object. Future enhancements may include more complex requests such as font request by size and style, and color request by RGB value.

PixShapes

Image data is supported through the LPixShape class. PixShapes are defined as raster-based images with 1 to 8 color planes and an optional transparency mask that allows the application to overlay multiple PixShapes. The transparency feature allows an application to build complex images from a number of simple PixShapes. PixShapes can either be defined in the program code as static initialized data or may be read in from files. We support the TIFF file format because it is one of the most widely used image data standards used within the computer industry.

Implications

We have implemented the Screen class hierarchy under X Windows and Curses. It is interesting to note that these environments are entirely different. X Windows is an extremely rich graphical environment that has become an industry standard among Unix workstations while Curses is a text mode based display package that traces its roots back to character terminals used on multi-user Unix systems. While we strongly believe that graphical environments are an important part of future AAC systems, the Curses based implementation provided an excellent opportunity to test design concepts related to issues of portability. We feel that our success in supporting two widely disparate environments attests to the achievement of our design goals, and we feel confident about future ports of the software.

Discussion

As stated previously, the current implementation is running on Sun Workstations and is actively being used by our project group. The software could be made available to any developers who are interested. In the future we plan to enhance the software in a number of ways. These include:

- Support for multiple windows
- Richer resource support
- Additional drawing primitives (as needed)
- Additional hardware/operating system support

This last goal is the most important. While Sun workstations provide an excellent platform for software research and development, we are fully aware of the need to support computers that could be used as AAC systems. In the near future, we plan to begin porting the toolkit to the Microsoft Windows environment and would be interested in discussing the prospects of an Apple Macintosh port with any other interested developers.

Acknowledgments

This work is supported by Grant Number H133E80015 from the National Institute on Disability and Rehabilitation Research. Additional support has been provided by the Nemours Foundation.

References

Mark A. Linton, Paul R. Calder, and John M. Vlissides. Interviews A C++ graphical interface toolkit. Technical Report CSL-TR-88-358, Stanford University, July 1988.

Ball, E., and Demasco, P., "Adapt: an authoring language for a flexible AAC architecture", *RESNA'90: Proceeding of the 13th Annual Conference*, June 1990, submitted.

Demasco, P., Ball, E., and Kerly, P., "The Development of a Software Architecture for Communication Devices", *RESNA'89: Proceedings of the 12th Annual Conference*, June 1989, 216-217.

McDougal, J., Knysh, B. Devkumar, S., Shein, F., and Lee, K. *Computer-based Technology for Individuals with Physical Disabilities: Guidelines for Alternate Access Developers.* International Business Machines, 1988

Demasco, P., Ball, E., and Kerly, P., "A Software Object Library for Augmentative Communication Systems", *RESNA'90: Proceeding of the 13th Annual Conference*, June 1990, submitted.

Contact

Patrick Demasco
Applied Science and Engineering Laboratories
A.I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
Email: demasco@udel.edu

AN ENHANCED OPERATING SYSTEM FOR THE PRENTKE COMPANY TOUCH TALKER™ AND LIGHT TALKER™

Donald M. Spaeth, M.A. Rehabilitation Engineering
Prentke Romich Company, Wooster, Ohio
Semantic Compaction Systems, Pittsburgh, Pennsylvania

Abstract

Portable, voice ouput, augmentative communication aids have been manufactured by the Prentke Romich Company (PRC) since 1984. This article describes the development of an enhanced operating system for standard usage on all produced devices. The replacement ROM chip can also be easily installed on existing devices. The new operating system improves memory management, provides word processor style editing features, has a customizing feature to reconfigure the keyboard layout and contains powerful message building functions for conversation.

Background

The Touch Talker™and Light Talker™are portable, battery powered, voice ouput communication aids manufactured by the Prentke Romich Company. Both are equipped with text-to-speech voice synthesizers. Released in 1984, the first models were equipped with Echo™ speech synthesizers with a robotic quality voice. The SmoothTalker™ speech board was introduced in 1987 and the DECtalk™ speech board became available in 1990. Speech board upgrades are less expensive than the purchase of a brand new device.

Both the devices use Minspeak™, a unique vocabulary retrieval system developed and patented by Semantic Compaction Systems, Pittsburgh, Pennsylvania. By actuating two or three locations marked with icons, Minspeak system operaters can retrieve messages up to several hundred characters long. Because the icons used on the keys are rich in multiple associations, system operators can access vocabularies containing thousands of messages from a set of 70 to 80 icons.

The Touch Talker and Light Talker are both controlled by an RCA 1802, CMOS, 8 bit microprocessor with a 64 K address space. The Touch Talker is configured with 16K of ROM and 48K of RAM memory. The Light Talker has 24 K of ROM and 40K of RAM memory. The lower 16 K of ROM on the two systems is practically identical. The major differences between the devices are the input methods.

The Touch Talker can only accept input from its built in 128 key mechanical keyboard which is laid out as a matrix of 8 rows and 16 columns.

The Light Talker marks its input locations with a matrix of 128 Light emitting diodes (LED's). These LED's are also arranged in 8 rows and 16 columns. These LED's are illuminated sequentially and the associated locations can be triggered by an optical pointer. The optical pointer can be mounted on the system operaters's head or other suitable body surface. The Light Talker can also be operated with one or more single switches through row-column scanning, joystick directed-scanning, or Morse code. In all, there are 25 methods of input provided on the Light Talker. To support all these selection techniques requires the additional 8K of system ROM.

Statement of Problem

While state-of-the-art speech synthesizers have been made available for these products, the operating systems have remained virtually unchanged since 1985 except for small code modifications needed to support the newer speech boards.

Before joining PRCthe author worked three years as a technology consultant for the Pennsylvania Special Education Assistive Device Center and had frequent opportunities to talk with speech clinicians and disabled clients using the PRC devices. Consumers and clinicians have requested that the following features be added to the standard operating system.

1. **System operators want to store more messages than the current RAM memory can contain.** Advanced users can learn and recall over 3,000 unique icon sequences. More RAM memory or a tighter data structure that can store more messages in the existing RAM memory is needed.

2. **The standard operating system would be easier to program if it had more editing features.** When creating new messages, text that has scrolled off the display cannot be made to reappear for changes and the cursor cannot be moved back through previously entered text except by backspacing and erasing. If upon completion of a message, the first word is discovered to be mispronounced, the entire message must be retyped. Better editing features would allow these devices to be used as a writing aids as well as communication aids.

3. **Conversational messages could be more detailed if the output buffer held more words.** In 1984, it was believed that most Touch Talker and Light Talker system operators would communicate by retrieving long general purpose sentences directly from the device's memory. When speaking directly from memory, these devices can retrieve messages that are hundreds of characters long and process all phonetic corrections embedded in those messages. Currently, many system operators want to string together small vocabulary units to produce very specific conversational comments and requests. Stringing vocabulary units requires an output buffer, an area in memory where

the text retrieved from memory can be combined with spelled out items from the keyboard prior to speaking. The existing system only provides a 40 character output buffer (the length of the display). Whenever the user fills the 40 character display, he must speak the contents immediately even if it is not a complete thought. An additional problem occurs when messages are transferred from memory to the display buffer and then retransferred to the speech synthesizer. When a message is placed in the display buffer, the phonetic corrections are removed so that the text will appear with correct spelling. When the the contents of the display buffer is later sent to the synthesizer and spoken, the phonetic corrections are absent. Some of the text, especially proper names and foreign words, is mispronounced.

4. System operators could be better served if the icons on the Touch Talker keyboard or the Light Talker LED matrix could be relocated or enlarged after vocabulary is installed. The keyboard of the Touch Talker or LED matrix of the Light Talker can have any character, icon, or function assigned to any location on the user's custom overlay. However, this layout information has to be designated before vocabulary messages are installed. If a clinician wishes to change part of a layout design after programming in messages, all messages associated with the changed keys must be reentered. Many clinicians now prefer to use Minspeak Application Programs (MAP's™). These are large vocabularies packages designed for system operators with varing levels of maturity and cognitive skill. These come with preassigned keyboard layouts typically 128 locations with 'QWERTY' typewriter style character sets. There is presently no way to customize the icons without also reprogramming all the associated messages.

Rationale

The goal of this particular project was to substantially improve an existing product line; not to create a new product. Enhancing the operating system was especially intended to help the owners of approximately 7,000 devices already in use.

Hardware changes such as a newer microprocessor, bank switched RAM and ROM were considered and rejected for two reasons.

1. To develop such improvements would have required an entirely new main circuit board. Once getting in this deep, it is very tempting to put in a better display and power supply. A project that began as an upgrade has now become a new product with a long development timeline, many manufacturing issues and a higher cost to consumers.

2. For the retrofit market, the cost of the enhanced operating system could be reduced by between $50 and $100 if the new operating system could be installed in the field by the system operator or his helper instead of having to return the device to the factory and having the new hardware installed by a service technician. Field installation would also eliminate all the nuisances associated with shipping, insurance, vocabulary transfers, loaner devices and disruption of the client's speech therapy. To achieve field installation, no hardware changes could be made to the any of the circuit boards. Only the operating system EPROM could be changed. Fortunately, the 16K operating system EPROM chip used in Touch Talkers and Light Talkers can be easily accessed by removing a black plastic cover from the rear of the device case. A non-technical person can easily snap in the new system chip. A chip carrier eliminates the risk of crushing or misaligning any of the tiny chip pins.

The software upgrades also had to be conservative. Desirable as it was to accomplish all the above listed improvements, radical changes to the operating system were discouraged. Thousands of users are accustomed to the existing operating system. To introduce too many new features that were not logical extensions of the existing system would cause many system operators and clinicians to become confused and discouraged because the enhanced system was too much a departure from familiar ground.

It was also essential that the new system software be capable of reading the current vocabulary storage format; even if it subsequently converted that current vocabulary to a more compressed format to save RAM memory. Without this backwards compatibility, system operaters or clinicians would have to reenter all their vocabulary messages after installing the new operating system chip. It was also essential that existing Memory Transfer Interfaces (MTI's) be capable of copying the new vocabulary files to magnetic media on popular desktop computers. The MTI's are the standard way of moving and storing custom vocabulary files.

Design

The 1802 microprocessor is programmed with assembly language. Even if a suitable higher level language such as C or BASIC could be obtained, the small 16K ROM space could not have supported it. Because of the learning time required to become proficient in 1802 machine code and become familiar with the prior programmer's code, it was decided to assign this programming task to a single employee rather than putting together a development team.

Before embarking on changes, the original operating system code had to be moved to a suitable development environment. The PseudoCorp™ Dissassembler, Cross-assembler and Simulator were found to be best programming tools available for the developing the 1802. This software was also appropriate because it ran on MS DOS hardware widely available in the PRC Research and Development department.

In January of 1990, the hex code from a production 16K EPROM was uploaded to an IBM 286 AT and converted back into source code with a PseudoCorp disassembler. Using notes and listings from 1985, this source code was rebuilt until it would assemble to the same object code contained in the production EPROM chip. At this time, it was discovered that several thousand bytes of ROM were unused and available.

While PseudoCorp provides a simulator in its developer's package that can be used to observe execution of 1802 code on a PC monitor, the author used it only during the first three months of the project. As the author's familiarity with 1802 machine language and the communication aid hardware grew, he found it more efficient to transfer object code to an EPROM burner, make an EPROM, plug the EPROM in to an actual devise and debug code by observing the device's behavior. An incircuit microprocessor emulator could have saved additional debugging. As the the code grew, the time for each cross assembly approached five minutes. In October 1990, the project was moved to a Compaq 386SX computer which reduced cross assembly time to about one minute.

Development

Because the vocabulary storage format would effect all other functions, this feature was modified first. The author designed a new vocabulary data structure that eliminated three bytes for every stored message. In large vocabularies containing 2,600 to 3,000 messages, approximately 7,000 to 9,000 bytes are freed by this improvement. To make the new operating system work with older vocabularies, the system checks the the stored vocabulary contained in RAM whenever the device is turned on. If vocabulary is discovered to be in the old storage format, the system alerts the system operators and asks permission to convert the old vocabulary to the new, more compact format. With the system operator's consent, a conversion utility is called. The old vocabulary literally shrinks down to about 80% of its former size. The conversion process requires about six seconds but only has to be performed once. All vocabulary additions thereafter occur in the new format.

After designing the new storage format, new editing features were created. Right and left-hand arrow keys were defined as functions and behave like the arrow keys on word processors. In storage mode (creating new messages), the editor works with 16 bit variables and can address all the unused RAM memory. It is possible to develop and edit messages, speeches, songs and writing projects thousands of characters in length. The system was also modified to preserve writing projects in progress in the event of a power down.. The system routinely powers down after five minutes of inactivity to prevent battery discharge. The new operating system now saves writing projects instead of erasing them.

For conversing, the 40 character display buffer was replaced by two buffers containing 256 bytes each. As vocabulary units are retrieved from memory, the software splits them into a phonetic portion, correct for the speech synthesizer, and a text portion, appropriate for the visual display. The phonetic and text components are stored in the two separate buffers. The editing functions, Left Arrow, Right Arrow, Delete character, and Delete word are designed to execute simultaneously in both buffers. Any changes or insertions made to the the text buffer by the system operator are replicated in the speech buffer. Because these buffers often contain different numbers of characters, the editing functions must read special codes embedded in the spaces between words so that syncronization between the buffers doesn't break down. Conversational passages up to 256 characters in length can be constructed by combining small vocabulary units retrieved from memory with directly spellings from the keyboard.

To allow clinicians and system operators to rearrange their icons and functions on the front panel without having to reprogram all the associated messages, a keyboard reassignment table was devised. Every time a key is pressed on the Touch Talker (or an LED is optically read on the Light Talker), the software checks to see whether the hardware value of the key should be used or a different value contained in a RAM lookup table. The clinician can easily switch the communication aid between the hardware and software keyboard definations. There is also an authoring function provided that allows the clinician to revise the keyboard lookup table at any time. Icons can be moved anywhere on the front panel. In addition, icons can assume any size or shape definable with the 128 sized squares.

During 1990 the author rewrote about 70% of the source code to achieve the new operating system.

Evaluation

The Enhanced Minspeak operating system (EMOS) has undergone beta testing by seven speech and language clinicians and two consumers with disabilities. The beta testers stated that the EMOS met the clinical and operational goals of the project.

Discussion

Upgrading operating systems and application software is commonly done in the computer industry. IBM DOS has been repeatedly upgraded since 1980 as has the Macintosh™ computer operating system. Software upgrades are easy to distribute and can extend the useful life of hardware thus reducing costs to consumers. Upgraded software, if designed to behave like an earlier product can give consumers the advantages of a new product without requiring the training time a brand new product would require.

Acknowlegments

The author wishes to thank the many clinicians and persons with disabilities who reviewed his work and contributed to the final product.

Donald M. Spaeth
Semantic Compaction Systems
801 McNeilly Road
Pittsburgh, PA 15226

14.5

Miniaturizing AAC Devices

David H. Hershberger
Prentke Romich Company, Wooster, OH

Abstract

New technology such as surface-mount integrated circuits and powerful microcontrollers have been implemented to create a small AAC device which can be worn by the user. The successes and challenges of the design and development process are discussed.

Background

The early 1980's saw a major change in commercially available AAC devices. Low-cost microprocessors and widely available integrated memory circuits enabled developers to use microcomputers and dedicated systems to create systems that had the memory capacity and power to better address the communication needs of non-speaking users. Later, laptop computers and improved techniques for forming enclosures, along with advancements in microelectronics, allowed communication devices to become smaller and more portable. During this same time, memory access and organization methods were devised that enabled users to have larger working vocabularies which in turn created a need for more electronic memory.

This new technology has allowed designers to create portable communication systems. Today, most widely-used AAC devices are designed so the user can easily transport them wherever he/she needs to go. They are also designed so they can be operated while mounted to a wheelchair or bed as well as on a table or desk.

Statement of Problem

There is a need, however, for AAC devices which are more portable for ambulatory individuals; Devices which can be operated and used during normal daily activities such as walking, playing and riding in a school bus or automobile. Such a device should have the capacity to accommodate the needs of the individual during these tasks, it should also be designed to present minimum physical obstruction or inconvenience to the user.

To illustrate the size of the population who could benefit from such a device, reference is made to the long term loan program of Pennsylvania's Assistive Device Center (ADC). In the five years since the initiation of this program, 618 students with AAC needs have been provided with assistive technology. Of this group, 23% of the students have the ability to ambulate, some with the use of walkers (Assistive Device News, 1990). Although not a majority, the group of ambulatory students does represent a significant portion of the group.

Rationale

The purpose of this project was to create an AAC device for ambulatory individuals which could be worn by the user. In addition to being portable, the device was to have the memory capacity and flexibility to address the communication needs of the user.

For the design of such a device to be practical, the necessary circuitry and components must fit into a compact enclosure. Also, the user must be able to operate it with minimal physical effort. Several technical aspects make this project much more feasible now than in the past. First, currently available microcontrollers contain much of the support circuitry that was necessary for earlier microprocessors and controllers.

Secondly, static RAM has become less expensive and more compact. In general, human-sounding speech can be produced with substantially less circuitry using digitized speech rather than synthesized speech. One of the tradeoffs, however, is that digitized speech requires more memory for storing phrases than a synthesized speech system requires. While compact dynamic RAM has been available for some time, much more battery power is required to maintain dynamic memory than static memory. The new advances in static memory allows an adequate amount of memory to be maintained with a minimum amount of circuit board area and with smaller and lighter batteries.

Finally, surface-mount technology is now an affordable and practical alternative for lower-quantity production. This also greatly reduces the size and weight of the final product.

Design

A questionnaire was distributed to forty speech clinicians. The questionnaire asked the clinicians to list the features necessary or desirable in an AAC device for ambulatory individuals. The composite response provided the following recommendations: The device should be able to be worn by the user in a natural, unobstructing manner; it should be able to be easily programmed and customized by the user's clinician, parent or teacher; and it should be sturdy enough to withstand daily activities.

The design is built around Signetic's SC80C451 microcontroller. This controller has many features which make it conducive to miniaturization, including: seven 8-bit quasi-directional output ports, parallel printer interface, full duplex UART, two 16-bit counter/timers, and on-chip ROM. It is also available in a PLCC package.

Texas Instrument's TMS62828Ls are used for memory storage. These integrated circuits are static RAMs with a 128K x 8 storage capacity and are available in surface mount packages. Digitized speech processing is accomplished with Toshiba's 8830 surface mount integrated circuit.

Since all of the major components in the design are low-power CMOS integrated circuits, it is possible to use small NiCad battery cells to supply power to the device.

A second aspect of the design was packaging; that is, how the device could be worn by the user. Several packaging designs were investigated, but the final choice was a belt as shown in Figure 1. The small boxes on either side of the speaker unit contain the electronic components. A flat cable connects these units together, but the support for the boxes is provided by the belt. A belt proved to be a natural method for wearing this device.

Development

Development of the project was started in September 1990. The software was developed on an IBM PC with the help of an in-circuit emulator made by Nohau for the 80C451. Initial development was performed on a wire-wrapped circuit board before moving to a surface mount circuit board in early 1991.

To assure that the device met the communication needs of the individual, the operation was patterned after a commercially available and successful communication aid -- Prentke Romich Company's Introtalker. While this device is somewhat limited in its spontaneous speech and memory capacity, past experience led us to believe that it would meet the needs of the individuals we were targeting.

One of the challenges in developing this device was to design a keyboard that the user could use to easily operate the device. While the belt (in Figure 1) provides for mounting and wearing the main device, individual client needs and abilities effect the type of keyboard that can be used and limit the mounting options. For this reason, the PRC Bus (Hershberger 1990) was incorporated as a keyboard connector. The PRC Bus gave us the greatest flexibility for allowing a variety of different keyboards or scanning devices to connect to the unit with a simple phone cord connection.

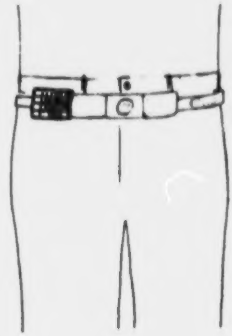


Figure 2. Belt-Mounted Keyboard

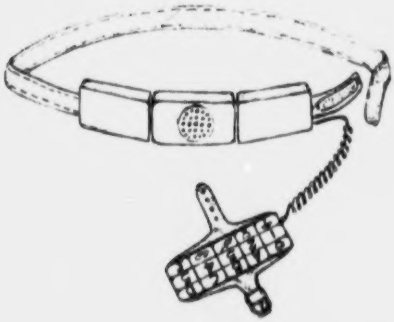


Figure 1. Belt design for mounting the device to the user.

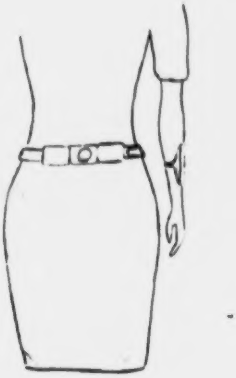


Figure 3. Wrist-Mounted Keyboard

Evaluation

As previously stated, while the design provides for mounting and wearing the main unit, the keyboard also must be worn or carried by the user. This proved to be the most challenging aspect of evaluation. While the size of the necessary electronics can be reduced, the number and size of the keys often dictate the physical surface area of the keyboard. The needs of the individual clients called for a number of different keyboard configurations. We have experimented with several designs; wrist-mounted, fold-down chest-mounted and a keyboard that also mounts to a belt. Two of these designs can be seen in Figures 2 and 3. Additional keyboard development and evaluation is planned for the future.

Discussion

'Wearable' assistive devices have been a dream of rehabilitation professionals for some time. As technology advances, so will creative implementations of the technology. This project helped to convince us that today's technology allows us to create devices that are small enough to wear. There is no reason to believe that current trends will not continue to make this a more practical alternative. Programmable gate arrays, better batteries and more integrated microcontrollers will help to make assistive devices even smaller in the next few years.

On the other hand, the project also made us aware of some of the challenges that we will face as we continue to develop smaller AAC devices. Connecting to more powerful assistive devices and/or computers, better portable access methods and improved mounting systems are issues which we need to face and solve in the next few years. The system in this project also lacked some of the features that have proven to be successful in other AAC devices; including an LCD display, synthetic speech and full size keyboard. Further research is required to determine how each of these necessary parts can be combined into a very functional and portable communication device.

Acknowledgements

Special thanks is given to Martin King, Cliff Kushler, Ed Gasser and Greg Carr for their assistance in this project.

References

"History of Long Term Loan Program." Assistive Device News Vol. 7, No. 1, (Fall, 1990), p. 2.

Hershberger, D. (1990) Connecting Peripherals to AAC Systems through a Common Communication Bus. Proceedings of the RESNA 13th Annual Conference, 10, pp. 95-96.

David H. Hershberger
Director of Research and Development
Prentke Romich Co.
1022 Heyl Rd.
Wooster, OH 44691

INFANTS WITH DISABILITIES AND THEIR FAMILIES: A CONCEPTUAL MODEL FOR TECHNOLOGY ASSESSMENT

Alan VanBiervliet, H. Phillips Parette, Jr. , & Robert H. Bradley
Center for Research on Teaching and Learning
University of Arkansas at Little Rock
Little Rock, Arkansas, 72204 USA

Abstract — A conceptual model for the comprehensive assessment of the technology needs of infants and their families is presented. The model evolves from the dictates of both P.L. 100-407 and P.L. 99-457 and from ecological/developmental and family systems theories. Implications for the development of future assessment strategies are addressed .

Background

A frequently expressed need of parents of children with disabilities is technology and related services to facilitate their children's optimal interactions with the environment (Parette & VanBiervliet, in press). A crucial component to the success of technology-assisted interventions for a young child with disabilities is the involvement of the child's family in the planning and implementation processes. The involvement of families in developing systems of technology-related assistance is mandated in P.L. 100-407, the *Technology-Related Assistance for Individuals with Disabilities Act of 1988.* Similarly, families are an integral part of the development of individualized family service plans (IFSPs) under Part H of P.L. 99-457, the *Education of the Handicapped Amendments of 1986.* Even with a high level of family involvement in planning, technology which may be provided as part of the plan does not guarantee an improved quality of life for either the family or child.

Statement of the Problem

The recent increase in the development of assistive technology service delivery systems has generated a number of issues which have not been addressed by empirical research. Quite often the introduction of assistive devices in the lives of children with disabilities represents a significant event both for the child and the entire family. The impact of introducing an assistive device on both child and family - and in particular the success in accomplishing the goals for which the device is intended - may well depend on a number of factors present in child and family at the time of introduction and during the transition which follows. Assistive technologies often require additions to family routines (e.g., battery charging or cleaning), restrictions of family activities (e.g., hindrance on travel due to size/portability of a wheelchair), and modifications to the home environment (e.g., setting aside "protected" space for a video enlarger system). Changes to family structure and environments as described above can be highly disruptive to family functioning. Such changes can adversely affect a family's ability to cope with stress, such as money problems or interpersonal clashes, and thereby have an negative effect on the child's development. Disruptions caused by the introduction of assistive technologies may even effect the family's sustainability or ability to remain a family unit resulting in marital separations or divorces. Some assistive technologies, such as large respirators, might even effect the development and maintenance of family attachments.

It is very likely that the failure of many early intervention programs involving assistive technologies is due at least partially to the lack of consideration of ecological and family functioning issues. Current assessment procedures that focus only on the child's behavior (e.g., range of motion) may erroneously claim an intervention to be successful, when in fact the program unnecessarily added to family stress factors resulting in the break up of the family unit. Since many assistive technologies may effect not only the child but the whole family, it appears to be very important to consider family and ecological factors before prescribing assistive technologies, and to evaluate the impact on the family by the device following its introduction and regular periods thereafter. Such an evaluation is entirely in keeping with the family oriented spirit of P.L. 99-457 and the concept of IFSPs.

Current assessment or evaluation approaches for assistive technologies focus on the measurement of child behavioral strengths and weaknesses. While this clearly provides important information for prescription and evaluation of assistive technologies, these procedures fail to take into consideration the impact of the child's technology on family functioning. There is also very little information about the likely impact that various technologies will have on the child and his/her family. Although some assistive technology quality indicators that have been developed emphasize the involvement of families in all aspects of program development and implementation, the measured effects of this involvement are limited to satisfaction and service effectiveness indices (S.M.A.R.T. Exchange, 1989). Limited attention has been directed toward the impact that the provision of technology has on the functioning of the child and family within the home environment. This places families, professionals and policy makers in the position of having limited information for developing, implementing, and evaluating systems of technology-related assistance for early intervention programs. Similarly, little instrumentation exists which can assist families and professionals in identifying children who could be most appropriate recipients of particular technologies in the context of the ecological environments in which they live.

Approach

Since child and family functioning is crucial to the success of any early intervention program, an ecological/developmental model, such as that described by

Belsky (1984) as a "parenting process" model, and the family systems models used by researchers in the area of disabilities (Dunst, Trivette, & Deal, 1987; Turnbull, Summers, & Brotherson, 1986) provide a basis for revising assessment strategies. These models incorporate consideration of family structure, interaction styles, interpersonal relationships, cultural factors, health and well-being, family stresses, coping styles, and family resources.

The comprehensive evaluation model proposes that information be gathered in four domains (child, family, assistive technology, and service system). Child factors include needs of the child, his or her capabilities, interests and goals. Family factors include background variables, needs, strengths, styles, resources, and preferences. Technology factors include demands placed on the child/family and opportunities which are presented by the introduction of technology. Service system factors include such characteristics as limitations, demands, and resources available to the family.

An important feature of the assessment model is the examination and monitoring of linkages within and among the four domains. This examination includes monitoring changes in each component; anticipating transitions between and interactions among components; a sensitivity to detecting serious problems; and approaches to detect unanticipated outcomes.

In developing models for assessment of technology needs, caution must be exercised to maintain a reality-based approach, i.e., recognizing that limitations on resources must somehow be balanced with the needs of children and families. The model basically entails a non-linear assessment procedure which maximizes the attainment of critical information using a low demand/high yield conceptual approach. Some variables are considered more *salient*, or exhibit more leverage on family functioning and decision-making. For example, meeting basic needs would exert particularly strong leverage on a family and its decision-making processes. Some variables would potentially be more *volatile*, or increase the probability of problems occurring. For example, any practice or demand which would increase caregiving demands placed on parents could exacerbate existing stress. Finally, some variables would potentially be more *vulnerable*, or be more susceptible to intervention impact. Transportation to and from needed services would be positively received by most families.

The evaluation process begins with gathering general information about the child and his/her family. Based on the review of this information, the clinician decides on which strategy to use in order to gather information for the next level of decisions. This progression from general to specific continues until sufficient information is gathered in order to create an effective intervention program.

The proposed assessment and planning model is very similar to making a "key", in which the lathing process is non-linear. The creation of the key results in a unique set of recommendations that can unlock the door of a more promising future for the child and his/her family by insuring that assistive technology needs are most appropriately identified and provided. The key consists of four layers or metals fused into an interconnected whole; the layers represent the four domains (child, family, assistive technology, and service system). As information is obtained from the assessment strategies the blank key is gradually honed into an individualized solution for a child and his/her family.

Implications

The comprehensive assessment model described above suggests perhaps that only a superhuman with a wide variety of skills in numerous disciplines could carry out the processes. The model, however, requires a team effort rather than a "Lone Ranger" approach. Professionals from human service, educational, therapy, and medical disciplines can combine their expertise with the input of the family to develop a successful plan for the child.

The non-linear assessment approach that is presented in this model diverges substantially from "battery" approaches whereby all children are evaluated with the same set of instruments. The non-linear approach incorporates a number of decision points in the progression from general to specific assessment strategies. At these decision points the team decides what assessment strategy or what information is necessary to complete the child's plan. By conducting only needed evaluation procedures, the non-linear assessment approach can prove to be cost effective and efficient. The incorporation of artificial intelligence technologies into the assessment process could assist in ensuring that decisions are based on a thorough analysis of available information.

Discussion

Family assessment is a source of valuable information when developing IFSPs for families of infants with disabilities. Given the increasingly important role which technology plays in the design and implementation of IFSPs, professionals are challenged to examine numerous issues relating to the assessment of families. Though instrumentation has yet to be developed which embodies these many issues, there is a clear need for new models to be conceptualized that will guide future assessment strategies. A comprehensive assessment model is presented which may guide the development of future assessment strategies. The result of the approach is a "key" of recommendations that is unique for each family. The key evolves from multiple levels of assessment which include the child, family, technology, and service systems factors.

Future family assessment strategies should embrace the philosophy that the manner in which family needs are addressed has an impact upon the development of infants with disabilities. Access, manipulation, and control of information and the environment will be a critical skill for all citizens in our society in the decades ahead (Cain & Taber, 1987). Aided by the tools of assistive technology and services, families can help their children attain a level of ultimate functioning (Brown, Nietupski, & Hamre-Nietupski, 1976), with devices and services becoming naturally assimilated as a part of their environment (Hansen & Perlman, 1989). When family needs are addressed, and families are given information to make informed decisions to help their children, parental expectations of their children's potential may be substantially altered, and the outcomes of interventions may be greatly enhanced.

Acknowledgements

Funding for this research was provided by the University of Arkansas - University Affiliated Programs in Developmental Disabilities, Grant Number 06DD0405, from the U.S. Department of Health, Administration on Developmental Disabilities.

References

1. Bailey, D., & Simeonsson, R. (1985). *Family needs survey*. Chapel Hill: Frank Porter Graham, Child Development Center, Univ. of North Carolina.
2. Brown, L., Nietupski, J., & Hamre-Nietupski, S. (1976). In M. A. Thomas (Ed.), *Hey, don't forget about me!* (pp. 2-15). Reston, VA: Council for Exceptional Children.
3. Cain, E. J., & Taber, F. M. (1987). *Educating disabled people for the 21st century*. Boston: Little, Brown, & Co.
4. Dunst, C. J., Trivette, C. M., & Deal, A. G. (1987). *Enabling and empowering families. Principles and guidelines for practice*. Morgantown, NC: Western Carolina Center.
5. Hansen, C. E., & Perlman, L. G. (1989). Technology: A vital tool for persons with disabilities. *Journal of Rehabilitation, 55*, 18-21.
6. Parette, H. P., & VanBiervliet, A. (in press). Rehabilitation issues for infants and young children with disabilities. *Journal of Rehabilitation*.
7. Sheehan, R., & Sites, J. (1989). Implications of P.L. 99-457 for assessment. *Topics in Early Childhood Special Education, 8*, 103-115.
8. SMART Exchange. (1989). *Quality indicators applicable to assistive technology service delivery programs*. Atlanta, GA: Author.
9. Trivette, C., Deal, A., & Dunst, C. (1986). Family needs, sources of support and professional roles: Critical elements of family systems assessment and intervention. *Diagnostique, 11*, 246-267.
10. Turnbull, A. P., Summers, J. A., & Brotherson, M. J. (1986). Family life cycle: Theoretical and empirical implications and future directions for families with mentally retarded members. In J. J. Gallagher & P. Vietze (Eds.), *Families of handicapped persons* Baltimore: Paul H. Brookes.

Alan VanBiervliet, Ph.D.
Center for Research on Teaching and Learning
University of Arkansas at Little Rock
2801 South University
Little Rock, AR 72204

15.2

Adaptive Equipment Design for Special Education by Interdisciplinary Undergraduate Students

William A. Hyman, Laura Dominguez*, Carolle L. Bass
and Gerald E. Miller
Bioenginering and Special Education* Programs
Texas A&M University, College Station, TX

Abstract

Undergraduate university students were used as a resource for meeting needs for adaptive equipment in preschool and special education. Participating students included bioengineering and education majors, with supervision by graduate students and faculty. The teams met with teachers, therapists and clients to define objectives and possible solutions. The teams then developed these solutions and returned finished devices to the originating setting. Projects included devices for classroom use and equipment for physical, occupational and speech therapy. The spectrum of needs met demonstrates feasibility and utility for adoption in other settings.

Background

One of the challenges in the delivery of special education and preschool adaptive technology is the cost effective inclusion of a custom design and modification service. This is especially true where the training of teachers and therapists has not included a strong technical component, and where the cost of providing this kind of service with additional staff or outside consultants is prohibitive. This has continued at the local level despite extensive national attention to the need for both off-the-shelf and customized adaptive technology (Cain and Taber, 1987; Campbell, et al, 1980; Burkhart, 1987; Lahm, 1989). The availability of commercial adaptive equipment has not fully addressed this area, nor has the development of resource guides (Enders, 1989) and data bases (ABLEDATA, SERIES, SPECIALNET). Commercial devices are often expensive, difficult to adequately select, and may require adaptation to the particular user. Resource guides and data bases can provide extensive information. However, even if these resources are used effectively, there is still a need for on site modification and custom design.

Objective

The program described here used teams of undergraduate university students to provide a design resource to local schools and a community infant and preschool program. The university students included majors in bioengineering and education who earned class credits for their participation. From the perspective of the off-campus clients, the objective of the program was to provide direct assistance in evaluating the needs of individual children, and in building or modifying equipment that what would meet these needs. The program also had the objectives of improving the technical awareness and expertise of present and future classroom teachers, increasing the understanding of the needs of individuals with handicaps, providing "real world" design experience, and demonstrating that this kind of program could bring a useful, low cost service to local school districts and community providers.

Method

The program involved on site visits by the participating university students to local schools, and a preschool center. During these visits the university students would interact with teachers and therapists, and their clients, to define educational and developmental needs that could be addressed through the design and fabrication of adaptive equipment, or the modification of existing adaptive or consumer products. Following these initial visits the students would look for existing solutions. If none was found they would then develop design alternatives for meeting the needs, obtain internal and external design reviews, refine the design, and ultimately build the device and return with it to the classroom or therapy setting for implementation. Where necessary further iteration was then undertaken. The education majors played an important role in helping to define the educational or developmental objective of each project. Supervision was provided by two graduate students, one in bioengineering and one in special education, and by participating members of the bioengineering faculty. The faculty guided the students throughout the design cycle to help assure successful completion including functionality, reliability and safety. The faculty also provided guidance on feasibility in terms of cost and time constraints. Coordination within the local school district was through the special education director, classroom teachers at the elementary, middle school and high school levels, and with the district's physical, occupational and music therapists. The preschool setting also involved physical and occupational therapists, along with speech therapists.

A well equipped design laboratory was available at the university to support this effort. This facility was supplemented where necessary by other university mechanical and electronic fabrication facilities. As a result of the funding for this project there was no cost to the school district for any of the devices provided. However, even without direct funding, the actual cost of construction of the devices was generally low compared to commercial counterparts. These costs would have been the only expense to the school district.

Results

The direct results of this program was the delivery of customized devices which met the specific needs of the participating teachers, therapists, and clients. These included devices for occupational, physical, speech and music therapy, as well as for daily classroom use.

Devices for P.T. and O.T. included portable vestibular boards, prone scooter boards including one with musical sounds, heel switch reminders for heel contact during walking, timed posture reminders, and an adjustable height transfer box for teaching wheelchair transfers. A multi-handle/multi-door device was also designed for training of these functions. Another group of projects involved mobility aids including a peg wheelchair rim for a small wheelchair, a low-to-ground wheelchair for foot propulsion, and hand cranked and hand-to-wheel user propelled carts. Several versions of voice/sound activated devices for speech therapy were also developed.

Projects were also completed in cooperation with the district's music therapist. One of these was a joy stick controlled musical keyboard which provided for one hand, limited mobility operation of an electronic music keyboard. This project was followed by the modification of electronic drum sticks to allow for operation by a downward slapping motion rather than requiring the user to hold the drum stick. Accommodation of more limited physical ability was provided by a switch operated motorized ukulele strummer and a switch operated chime striker.

Classroom devices included wheelchair tray designs and modifications to accommodate individual users. Several furniture projects were also undertaken included a small kneeling chair, an adjustable corner chair, a lock-in-place desk, and a back lighted table for low vision users. A delayed action chime was provided which allowed for student response without encouraging repeated activation for random noise making. Projects for self feeding included utensil modifications and a compartmentalized lunch tray warmer to maintain food temperature during slow eating. Other projects included modification of a button maker to accommodate the physical limitations of the intended users, modifications of standers to limit lifting of children by teachers, an item placement and counting reward system, and a name trace system which provided feedback when a "pen" remained on a pattern of the individual child's name.

In addition to specific projects the presence of the teams in the classroom facilitated consulting opportunities during which immediate solutions to some needs were suggested, small repairs made, and computer systems installed and/or explained to on site personnel.

Discussion

The completion of these projects provided a direct benefit to the educational and therapeutic goals of the preschool and school settings for which they were developed. In most cases they represented solutions to needs that would not have been readily met, if at all, without the direct contribution of this program. It is noteworthy that the projects requested by teachers and therapists, and implemented in this program, are generally not very demanding from a technological perspective and are not related to computers. One possible explanation for this is that at the initiation of the project there was a built up demand for relatively simple things because of the inadequate technical resources previously available. It may also be that the teachers and therapists are not prepared by training or experience to define more complex needs, or that some of these needs are being met from other resources. In either case, as the program progresses it may be that more complex needs will be identified as simpler needs are met and appreciation of technology is enhanced.

In addition to meeting clear needs, the broader objective of influencing the training and career orientation of the participating undergraduates is more difficult to assess in the short term. However the experience of one participant is evidence of the value of this kind of program. This student began participating as a senior education major, and then became one of the supervising graduate students. In that capacity she played a major liaison role with the school district thereby gaining broad experience in classroom needs and technological approaches. She can be expected to carry these experiences into the rest of her graduate education and teaching career.

The additional objective of providing a model for duplication elsewhere has been achieved by clearly demonstrating that undergraduate design teams can provide a valuable resource in the special education and therapy setting.

References

ABBLEDATA, Adaptive Equipment Center, Newington Children's Hospital, Newington, CN.

Burkhart, LJ, Using Computers and Speech Synthesis to Facilitate Communicative Interaction with Young and/or Severely Handicapped Children, L.J. Burkhart Publisher, College Park MD, 1987.

Cain, EJ and Taber FM, Educating Disabled People for the 21st Century, Little, Brown & Co, Boston, 1987.

Campbell, PH, Bricker, WA, and Espositio, L, "Technology in the education of the severely handicapped". In B. Wilcox and B. York (Eds.), Quality Education for the Severely Handicapped, U.S. Dept. of Education, 1980.

Enders, A, Assistive Technology Sourcebook, RESNA Press, Washington, DC, 1989.

Lahm, EA (Ed.), "Technology with Low Incidence Populations: Promoting Access to Education and Learning", Center for Special Education, Council for Exceptional Children, Reston, VA, 1989.

SERIES, Center On Human Development, University of Oregon, Eugene, OR.

SPECIALNET, GTE Educational Services, Washington, DC.

Acknowledgments

Funding for the work described here was provided by grant number H133C90069 from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, and by grant number EET 8805377 from the Biomedical Engineering and Aiding the Disabled Program of the National Science Foundation.

William A. Hyman
Bioengineering Program
Texas A&M University
College Station, Texas 77840

15.3

COMPREHENSIVE TRAINING ON ASSISTIVE TECHNOLOGY: A FUNCTIONAL STUDENT-CENTERED APPROACH

Elizabeth A. Lahm
Center for Special Education Technology
The Council for Exceptional Children
Reston, VA 22091

ABSTRACT

In response to an expressed need of trainers, the Center for Special Education Technology developed a comprehensive outline of assistive technology applications for school-age children. The result of the Center's efforts is a dynamic curriculum outline that provides an alternative approach to technology-specific training. The student is the focus and the technology is presented as one potential solution for providing better access to instruction in schools. After extensive input from experienced trainers and experts in assistive technology utilization, the Center offers this outline as a resource to the special education technology field.

BACKGROUND

Technology, in its many facets, is rapidly coming to permeate today's educational settings, not the least of which are the special education classrooms. Assistive technology, and all that it implies, is quickly moving into these classrooms because it provides access to instruction to many students with disabilities. These students can access, maintain, and improve their functioning in learning, living, work, and recreation environments through the proper use of technology.

In early 1989 the Center consulted a group of assistive technology experts who identified a need for an outline to assist trainers in comprehensive coverage of assistive technology applications. They cautioned that a curriculum must not promote a "technology for technology's sake" approach and must be truly comprehensive in nature. With those directives, the development of this outline was pursued.

The result of the Center's efforts is a curriculum outline that provides an alternative approach to technology-specific training. The student is the focus and the technology is presented as one potential solution for providing better access to instruction in schools. Functional tasks required in the learning environment are the framework for examining these potential solutions. It is hoped that this unique approach will allow the trainer to think beyond the standard technology solutions and look closely at the capability of the technology and match it with the requirements of functional tasks that a student cannot perform without assistance.

OBJECTIVE

Although many school districts are beginning to address the training needs of their teachers and related service personnel in the area of assistive technology, the history of the training has been relatively short and patterns show a tendency to focus on the technology rather than the learner and often the trainer lacks comprehensiveness. The Center's objective was to develop a curriculum designed for trainers that addressed those two concerns.

It was also recognized that training is conducted following many models, both at the pre- and inservice levels. Consequently, it became another objective to have the outline be flexible enough to meet the needs of a diverse group of trainers.

METHOD/APPROACH

Center staff began the development process by pulling together various components that would be needed to address the expressed needs for comprehensiveness and learner-based. The outline format was chosen to keep the curriculum flexible enough to meet individual trainer's needs. Resources and references would serve to direct individuals to needed content information.

Two committees of experts were identified to review the initial draft, one committee with expertise in assistive technology and the other with expertise in technology training. Audio conferences were held with each group to discuss the content of the outline and the usefulness of the format. Based on feedback from these two groups, the curriculum outline was revised.

A second round of audio conferences were held with the revised draft. When recommended changes were incorporated into the document, further field review was sought.

Two field review procedures were pursued. Ten additional technology and disability experts agreed to review the manuscript. Their feedback was received individually in written form. Additionally, trainers were invited to attend a presentation of the curriculum outline at a national conference, providing interactive feedback from a self-selected group of reviewers. After final changes were made, the curriculum outline was sent to approximately 300 trainers and service providers. Approximately nine months later, feedback questionnaires were sent to these individuals soliciting information about the usefulness of the outline.

RESULTS

After extensive input from experienced trainers and experts in assistive technology utilization, the Center offers this outline as a resource to the special education technology field. What follows are the training modules of the curriculum outline, organized by functional educational tasks required of students.

A Student-Centered Approach
Reading
Speaking
Writing/Manipulating
Seeing/Visual Processing
Hearing/Listening
Cognitive Processing
Multiple Disabilities
Implementation and Related Issues

Each training module addresses student assessment, technologies that provide potential solutions to barriers or access to instruction, and training references.

An extensive references and resources section concludes the curriculum to provide the trainer with ample information sources for developing a training program that meets their needs. This section is divided into the following:

Selected Readings
Selected Training Materials
Selected Curricula
Selected Newsletters/Journals
Directories of Database Information

DISCUSSION

Once all field feedback information is in and reviewed, the Center. plans to revise the outline one more time. It is anticipated that this will occur during the summer of 1991. Interested technology trainers can contact the Center for information about its availability.

ACKNOWLEDGMENTS

The project is funded by the Office of Special Education Programs, U.S. Department of Education under Contract No. 300-87-0115 and operated by The Council for Exceptional Children. For more information, contact the Center for Special Education Technology, CEC, 1920 Association Drive, Reston, VA 22091 or call 800/873-8255.

Toward a Switch-Smart GUI

Charles Silverman, M.Ed., Anne-Patrice Hickey, Ph.D.
CAST, Inc.
(Center for Applied Special Technology)

Abstract

Many present single-switch software and hardware solutions fall short of offering the comprehensive approach that school-aged children require in order to receive a fully accessible and equal education. This paper takes the position that graphical user interfaces (GUI's) have the potential to offer the most comprehensive environment for single switch users and their teachers, both as a comprehensive learning tool and as an access solution.

The Problem

Students who require single-switch solutions to accessing computers in the classroom have a set of needs which are qualitatively different than their able-bodied peers. For the single-switch user, the computer provides the sole means of access to their curriculum. Paper, pencil, crayon, and even recreation should ideally be computer-based as the goal is to enable the single switch user to be active, interactive, and independent participant in all school-based activities. For the student who depends on a single switch in order to control the computer, the computer has the potential to become the equivalent of an electronically smart desk.

Two levels of single switch solutions currently exist. Scanning may be available through 1) a dedicated application or 2) a system-wide approach, implemented either through hardware or software (e.g., the Adaptive Firmware Card, Handi-keys, Kenix). Each approach offers the user advantages and disadvantages.

Dedicated applications present an interface that is integrated in functionality and design. If the student needs to select one of several objects on the screen, those objects are scanned. As such, dedicated applications have the potential to be both intuitive and efficient. As a result, students can more readily concentrate on the contents of the application, rather than the mechanics of scanning.

While the dedicated scanning software solution may be appealing, there is a limited number of scanning applications. The quality of these applications is inconsistent with many being in the public domain. Commerically available scanning titles are often copy-protected and unable to run on a hard drive. Students using copy-protected applications will require assistance in switching disks. Additionally, the commerically-based programs are produced by companies which are focused on the disabilities market rather than educational software development. Consequently, they do not have in-house resources or the necessary market base necessary to develop consistent, high quality programs.

System-based solutions offer the user access to "real world" software, but are frequently text based, and command-line oriented. The student's ultimate success in using this solution depends on both the student and teacher's computer skills. In a systems-type solution, such as the Adaptive Firmware Card, the student must be able to associate the letters presented in the scanning array character line (which superimposes itself on top of the program) with the actions required by the software. Since a systems-based solution is not aware of the application it is running, the user has two choices: 1) scanning the complete alphabet array in order to make a limited number of choices on a screen, or 2) editing the scanning arrays and make them appropriate to the software. Even with shorter arrays, the scanning setup may remain counter-intuitive in comparison to dedicated software. For some students, these counter-intuitive, character-based scanning approaches may make tasks much more difficult than having direct contact with the objects in a manner closer to what dedicated software offers.

Toward a "Switch Smart" Alternative

The ideal solution is to combine features of the systems-based approach and that of the dedicated scanning application. The building blocks of a scanning interface exist within a GUI. Consider that the GUI is set up so that the (able-bodied) user visually "scans" these possiblities and decides on a selection, first by visually locating it, and then physically, by moving a pointer over the object, and selecting it. Additionally, the user may want to drag the object to another part of the screen. Menu bars provide a means to access program commands, and specialized tools are provided in the form of floating windows. The primary action in this environment is pointing and clicking.

The single switch environment is one of scanning the available actions, and making a selection. Buttons may be hilighted, and text as well. A keyboard representation lives in a screen window which appears to be well-integrated into the program. A smart scanning environment implemented on a system level in a GUI environment should also be aware of program objects (i.e., buttons, menus, windows, and text fields). This results in "switch smart" applications.

Two recently developed applications will serve to illustrate the potential of a switch-smart, system-based environment. **HyperScreen** (Scholastic) is a graphical environment based on the Macintosh and HyperCard for the Apple II series computer. As such, it offers a point-and-click construction environment. Teachers and students can use **HyperScreen** to produce lessons, reports, and presentations, called stacks, with a multimedia flair. Stacks consist of buttons and cards. Buttons live on top of objects on a card. The objects may be graphical or text-based. By clicking on these "hot-spots" the user moves from point to point, looking at information, graphics, and listening to sounds, music or voice.

HyperScreen's development included a commitment to make this software available to students who use single switches. In the scan mode, it identifies the number of buttons on the screen, and proceeds to highlight each one for a set period of time. Scanning-related features are available in the settings dialog box. Single switch users are able to navigate through HyperScreen created stacks and teachers are able to create software that is appropriate for their students.

Gateway (Don Johnston Developmental Equipment Corp. /CAST) further illustrates the concept of making use of existing features. This software is a collection of young children's stories. Developed in **HyperCard** on the Macintosh, **Gate-way** provides teachers and their students with a collection of stories in an accessible format. Standard **Hyper-Card** buttons provide navigational access between stories and within stories. While the interface is standard "point and click" GUI, users have access to a scanning mode. Under this mode, buttons are hilighted as they scan. The user presses a switch to make a selection. In addition, text can be highlighted and spoken. A Gateway authoring Template is also available, which provides a HyperCard template, necessary buttons, and directions for teacher creating stories.

In the two software examples cited above, scanning does not interfere with the interface, but harnesses integral features of the interface. Single switch scanning is easily added to these GUI-based programs. Scanning menubars, buttons, text selection highlighting, and the ability to locate and organize the"scan-able" features of an application are all critical if the single switch user is to benefit from this technology.

Summary

Who should develop the switch-smart system-level solutions? These solutions ought to be the responsibility of the system developers, in collaboration with professionals in special education and rehabilitation technology fields who possess a comprehensive understanding of the problems, solutions and limitations. With the adaptive features as part of the operating system, software developers can then add "smart-switch" information to their programs. The results would lead to a true electronic desk, barrier-free environment for students who use single switches.

REFERENCES

Brownlow, N., Shein, F., Thomas, D., Milner, M.,& Parnes, P. 1989. *Direct Manipulation: Its Significance for People with Disablilities. Proceedings of the RESNA. 12th Annual Conference*, pp. 244-245. Washington: RESNAPress

Cress, C. & Tew, J.. 1990. *Cognitive Skills Associated with the Operation of Various Computer Interfaces. Proceedings of the RESNA*. 13th Annual Conference, pp. 251-252. Washington: RESNAPress

Gateway (C)1990 Don Johnston Developmental Equipment Corp /CAST

HyperScreen (C) 1990 Scholastic / George Brackett

HyperCard is a trademark of Apple Computer Corporation.

Charles Silverman
CAST (Center for Applied Special Technology)
39 Cross Street
Peabody, MA 01960
617-531-8555
AppleLink X1217
CompuServe 74776,703

CENTERS OF ENERGY

Harry J. Murphy
California State University, Northridge

Introduction

Under a contract from the National Council on Disability, a report for national distribution is being prepared on sixteen model, exemplary university and college programs using technology as a support service with students with disabilities. The study is directed at the impact of these programs within and without their institutions.

Methods

The project director is conducting personal, on-site interviews at each center. Questions are directed at a) impact of the program within and without the university, b) relationship between "hard" and "soft" money and in some cases, institutional commitment when outside funding ceased, and c) advise to others who may want to start up a similar program.

Results

This is a report-in-progress. Half of the sites have been visited and interviews conducted. The major finding is that the model programs function as a "Center of Energy," a term coined by Dr. Trent Batson of Gallaudet University to describe his own model program, one of the sixteen under consideration in this study. They are "Centers of Energy," in that, often to their own surprise, their energy impacted their own institution and/or impacted external parties: Department of Rehabilitation, parents, school districts and other colleges and universities.

Other findings: (1) The initial contribution of the university or college was space. In some cases, the institution provided some equipment or personnel, but in most cases, the programs were started on external funding, and (2) the "Centers of Energy" were most helpful and candid in developing a "road map" for other institutions which included pitfalls, funding problems and successes that could be replicated elsewhere.

Discussion

The programs dealt with a broad range of technology applications from very sophisticated and well-equipped, major, urban universities and colleges to rural, simply equipped institutions. Each developed under a unique set of circumstances peculiar to the institution, the locale, the style of the founder and the availability of outside funding.

Because these programs were so new, the usual case was to interview the original founder of the program, so an accurate historical perspective was captured.

PERSONALIZED POWER WHEELCHAIR FOR A CEREBRAL-PALSIED ADOLESCENT

Theodore W. Cannon, Ph.D., P.E.
Solar Energy Research Institute

ABSTRACT

The author has personalized an Invacare Arrow XT power wheelchair for his 18-year old, non-verbal, cerebral-palsied son. A computer system consisting of an Apple IIc computer with customized miniature keyboard, DECtalk speech synthesizer, miniature printer and four-inch CRT monitor was installed on the chair. Additional amenities include a quick-release lap tray, full lighting system, storage compartments, fold-up utility table, pull hitch and annunciator. All electrical components are powered by the wheelchair battery.

BACKGROUND

The objectives of the present work are similar to those of a system developed previously by the author (1): to provide a means of electronic communication, to provide an on-board computer capability, and to enhance the utility, safety and enjoyment of the wheelchair. The new system has been installed on a 1990-model Invacare Arrow XT power wheelchair. Most noteworthy of improvements are development of a miniature keyboard for the Apple IIc computer, improvements in the communications software and development of a tilting utility table. Significant improvements were made in mechanical and electronic construction techniques to improve appearance and increase reliability and ease of access to all components.

STATEMENT OF THE PROBLEM

The author's son, Al Cannon, has severe athetoid cerebral palsy. He has essentially no control of his voluntary motor functions below the neck. Because he has good head control, he is able to drive a power wheelchair, but the wheelchair needed additional equipment to meet his communication, education, safety and entertainment needs.

RATIONALE

The improvements described in this paper allow Al to communicate electronically and run various computer programs by means of keyboard entry using a headstick. Additional features were added to make the chair more functional for him and his attendants.

DESIGN

This section describes the various components of the personalized power wheelchair.

Computer

An Apple IIc computer was installed in a compartment in the rear section of the wheelchair. This particular computer was chosen because it can run the ubiquitous Apple II software and can run on battery power. The Apple IIc has a 40-column mode, essential for readability on the four-inch monitor. The computer has two serial ports which are used in this application for speech synthesizer and printer outputs respectively. This computer can still be purchased used at a reasonable price. Access to the 5 1/4-inch disk drive is provided by a small door in the side of the computer compartment. The computer is mounted on a drawer which slides in and out, allowing access to the computer's connectors and for servicing.

Miniature keyboard

The regular Apple IIc keyboard was replaced by a remote, miniature (2/3-scale) keyboard mounted directly in front of the operator on a small, adjustable-tilt table. The keyboard housing is 8 3/4-inches wide, six-inches high and two-inches deep. The keys are on half-inch centers (vs. 3/4-inch for the normal keyboard). The date and time are continuously displayed via small electronic clocks mounted immediately above the key area.

The miniature keyboard not only reduces the overall space required, but reduces the overall range of motion and distance between keys, significant advantages to one having good control but limited range of headstick movement. The caps lock, shift, control, and open- and closed-Apple keys are all electronically toggled; all but the shift key automatically toggle off after a subsequent entry. Indicator lamps show the status of these five keys.

The keys which are most frequently used in the communications program are duplicated on a row immediately above the numerical keys.

Both the space and return keys are duplicated by large, vertically-mounted keys at the right side of the keyboard. These two keys are easily accessed by sideways motion of the headstick. Both audible and optical feedback indicate when an entry has been made. To lessen damage to the computer keyboard's decoder circuitry by static electricity, the keyboard circuitry is electrically isolated from the computer by use of optoisolators and power is supplied to the keyboard using an isolated, DC-DC converter; there is no common electrical ground between the keyboard and computer.

Printer and monitor

A small printer (Impact Printer II) can be mounted on the lap tray. Print speed is about 33 lines of 32 characters per line per minute on 2 1/2-inch adding machine paper. Printing is especially helpful when the synthesized speech cannot be understood or for making hard copy of messages or ideas.

The four-inch CRT monitor has adequate resolution to be readable with the computer in 40-column mode. It is not necessary to use the monitor with the communication program.

Speech synthesizer

The DECtalk speech synthesizer was chosen for its excellent speech quality. The portable, battery-powered model was chosen for this application. In addition to being small in size, it has a power saving feature which helps to extend battery life by shutting down some of the power-intensive circuitry when it is not speaking. The DECtalk is mounted directly under the seat and is powered from the wheelchair battery. A loudspeaker is mounted directly behind the operator's head.

The COKES augmentative communication system

A BASIC computer program called COmmunication by Keyboard Entry System (COKES) was written by the author several years ago (2,3). This program incorporates a simple but adequate text editor; the user can compose text either by code entry or direct spelling. The words are echoed by the synthesizer as they are entered. The entire text can be spoken and, if desired, printed on command. Codes, words or the entire text can be deleted as desired. Normally, the one-to-three digit (or more in a few cases) codes are entered followed by pressing the spacebar. An attention getter feature allows 26 words commonly used for socialization (i.e. hello, I want to talk to you) to be spoken immediately upon a single key entry; these words are not entered into the text. Coded words can easily be added or deleted from the COKES program using the BASIC editor.

Lighting system

A wheelchair lighting system is essential for the safe operation of the chair under reduced lighting conditions. The lighting system consists of right and left headlights, sidelights and taillights, making the chair visible from all directions while providing light for the path ahead. Additionally, a pair of lights has been installed near the tie down eye bolt so that it is easy to see to locate the chair immediately above the tie down rod on the floor of the van under subdued lighting conditions.

Utilities

Several utilities have been added to the chair.

A quick-release tray was fabricated from half-inch thick polycarbonate. The tray snaps into position in front of the seat and is easily released by simultaneously pulling out a spring-loaded pin on each side of the tray.

A 15.74-inch high, 11.81-inch wide, 7.87-inch deep compression molded, fiberglass, watertight cabinet was installed behind the seat. This cabinet is used for general storage and storage of the keyboard, printer and monitor when they are not in use. An additional open storage space immediately ahead of the cabinet is provided for school books, message book and other items.

A folding utility table was mounted on the outside of the storage cabinet door and is useful for holding cafeteria trays and food, medicine and drink containers. This table is always folded flat against the cabinet door when the chair is moving.

The annunciator is used to indicated when there are written messages for a teacher or parents. The annunciator lamp is turned on and flashes slowly if there is a message in the message book. The annunciator also buzzes every 25 minutes until the light is extinguished.

The pull hitch is used to attach wagons and toys to the wheelchair. Al enjoys pulling people in a wagon. The hitch could also be used to pull a grocery cart.

DEVELOPMENT

The development of the equipment and software described in this paper has taken place over an approximately four-year period from 1986 to 1990 and will continue, making use of improved technology as resources become available.

This work was done solely by the author and using the author's own funds and resources with the goal of helping Al, and possibly others, overcome very difficult obstacles imposed by severe cerebral palsy. This work demonstrates what can be done to help the handicapped by application of sound engineering practices and high technology.

EVALUATION

Evaluation of the equipment is an ongoing process both at home and at Al's school. The computer and augmentative speech components have proven to be of great value in giving him freedom of speech and access to all Apple II programs for his entertainment and education . The chair can be driven safely at night using the lighting system, and the other components have proven to be invalueable enhancements to the wheelchair.

DISCUSSION

Augmentative Communication and Computer Access

Al has communicated most of his life using the ETRAN-N system (4); he has memorized the codes for several hundred words and learned to used these codes with his teachers and family members with a high degree of effectiveness. This system has the disadvantage of requiring the listener to either know the codes or have access to a code list. Using the computerized COKES system (described above), he is able to speak with anyone near the wheelchair. We have found the combination of ETRAN-N and COKES to be very effective; ETRAN-N for use outside of the wheelchair or when the computer is not operational and COKES for use from the chair.

Having the computer installed in the wheelchair is convenient for all computer applications in addition to communications. Learning programs, games and other programs can easily be loaded into the computer. When the capabilities of the on-board printer and monitor are limiting, the cables can be reconnected to a regular off-board printer or monitor.

ACKNOWLEDGMENTS

The author wishes to thank Mr. Brian Costello for help with the design and construction of the miniature keyboard. I also wish to thank Jennie Carpenter, Connie Petterson, Mary Carpenter, Michael Poss, Kay Swanson and Robert Weiland, of Al's special education school for their encouragement and many helpful discussions.

REFERENCES

1. Cannon, T.W.: **Customized Wheelchair for a Cerebral-Palsied Adolescent**. Proceedings of the 10th Annual Conference on Rehabilitation Technology, San Jose: 1987

2. Cannon, T.W.: **An Optically Actuated Keyboard System**. Proceedings of the Johns Hopkins First National Search for Applications of Personal Computing to Aid the Handicapped, IEEE Computer Society Press: 1981

3. Cannon, T.W.:**Optically Actuated Keyboard System (OAKS) Word Processor for Physically Handicapped**. Proceedings: IEEE Region 5 Conference and Exposition, Colorado Springs, CO: 1982

4. Fishman,I.: **Electronic Communication Aids**. College-Hill Press: 1987

Dr. Theodore W. Cannon, Ph.D., P.E.
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

16.2

A User Survey on Backup Power for Powered Wheelchairs

James H. Aylor Hyuk Byun James J. Kauzlarich

University of Virginia Rehabilitation Engineering Center

Charlottesville, Virginia 22903

Abstract

One of the most important components of a powered wheelchair is the batteries. The problem, however, is that the component most frequently requiring repair is also the batteries. This paper presents a portion of the results of a survey developed and administered by the University of Virginia Rehabilitation Engineering Center. The survey attempted to obtain more detailed information on the type of problems encountered with battery failure. Additional information was also requested that can be used to help the UVa REC and others design systems that would make more efficient use of the powered wheelchair battery system.

Background

One of the most important components of a powered wheelchair is the batteries. Without a sufficient and reliable source of power, powered wheelchair users loose their mobility. Numerous surveys have indicated, however, that the batteries are also the component requiring the most frequent repair or replacement [1]. For example, for the survey reported on in [1], 71 percent of the respondents reported that they have had problems with their batteries. The next highest problem component was the tires, although only 47 percent reported to have had problems with the tires.

Very few advances have taken place in battery technology and technology supporting the care and maintenance of the batteries for the powered wheelchair. The predominate battery technology is still lead acid. Numerous battery chargers still tend to overcharge and battery monitors are not very accurate. In addition, the average powered wheelchair user is not well informed of the proper maintenance habits to insure maximum battery lifetime. Because of these issues, users experience premature battery failure and become stranded unnecessarily.

Technology is available to help this problem. Available energy can be efficiently managed with better capacity monitors and battery lifetime can be extended with properly charging electronics. More effective user feedback from the usage and charging process can improve the situation significantly. The main problem is to determine the actual needs and desires of the user community.

Objective

A survey of adult powered wheelchair users was conducted to ascertain the problems that they had experienced with batteries and supporting technologies such as monitors and chargers. The overall objective was to obtain information that could be used to guide the various research efforts in progress and to encourage funding agencies to support more research.

Method/Approach

The survey contained approximately 20 questions. Several questions were included that obtained information on the type of wheelchair used, frequency of use, and type of use (indoors, outdoors,ramps,etc.). Specific questions on the batteries were: (1) how often did they fail, (2) type of battery used, and (3) the recharge habits of the user. Battery condition meters were also covered in the survey. Finally, the users were surveyed as to their opinions on whether or not backup (reserve) power available during operation is a necessity. Backup power concerns the ability to provide enough power when stranded due to a low battery charge condition, and to be able to travel to a location where help is available.

Results

Approximately 308 surveys were mailed. To date, 56 surveys have been returned. A sample of the results is as follows. The respondents had a mean usage time of 4.04 years and a median usage time of 4 years. Most of their usage was indoors, paved outdoor areas and ramps. There

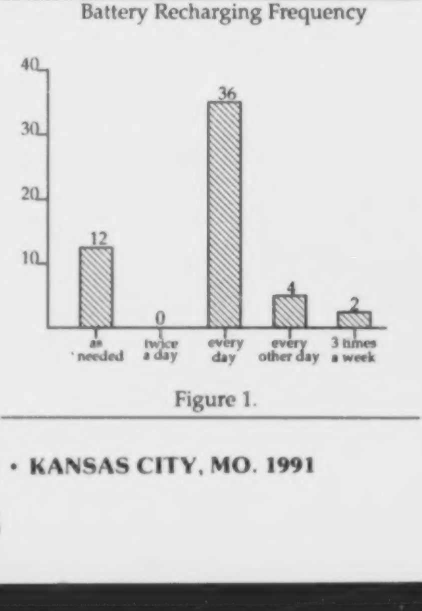


Figure 1.

was also some usage on off pavement surfaces, hills and public transportation. The survey indicated that people use their chairs for an average of 11.8 hours per day. Most respondents charge their batteries nightly and 91.84% of them recharge their batteries fully each time. Although not a daily requirement, people with wet batteries regard adding water as a real chore. On the average, water is added once every three months. Most people surveyed wanted maintenance-free batteries or a way to tell when and how much water was to be added.

The major improvement that the people wanted in battery technology was longer life per charge. Presently, a battery is charged on the average once every 1.16 days. The median value is one charge per day (Figure 1). As shown in Figure 2, 86.27% of the people surveyed wanted greater capacity but only 65.31% would accept larger size batteries to attain that extra performance (Figure 3). People who did not want the larger size battery indicated weight and size as their main concern.

Concerning the issue of back up power, most powered wheelchair users surveyed seemed to view it as a necessary part of the battery power system. On the average, the users of the power wheelchair are stranded 4.15 times per year due to the lack of power. As shown in Figure 4, 66.67% of the respondents desire some form of backup power. Most of them want an auxiliary power source which will provide enough energy to reach a telephone or other means of help when they become stranded. A possible solution could be to avoid the situation where power runs out through the use of a battery meter. However, the survey shows that only 57.41% of the power wheelchair owners have a battery meter.

Of the major issues addressed by the survey, users of the powered wheelchair want less maintenance of their battery, longer time of operation between charges and backup power. However, a fair number of people seemed to indicate backup power as a much needed feature. They feel that this feature will allow them to reach help when power fails on their wheelchair thus giving them an added feature of security.

People Wanting Greater Capacity

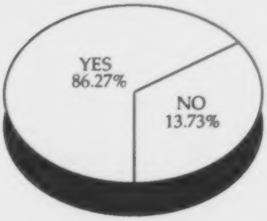


Figure 2.

People Willing to Accept Increase Size and Weight for Performance

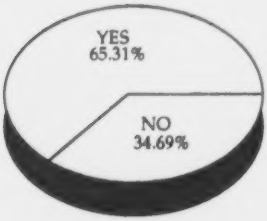


Figure 3.

Discussion

Although the answers to most of the questions were not surprising, exact statistics on some of the issues can be of use. People do get stranded, but it was surprising to the extent (64 percent of the respondents had been stranded). Because of this fact, most of the respondents feel that a backup power source or energy management strategy is needed. Costly batteries are being replaced often. In addition, people tend to want more capacity and are willing to accept the necessary increase in size and weight. Most people are receiving information on proper

People Wanting a Backup Power Source

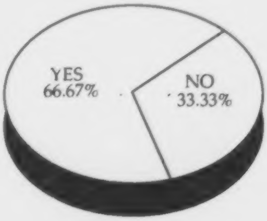


Figure 4.

maintenance and are, in general, following the instructions. Monitors are not being used to a great extent and are often considered unreliable and inaccurate.

The overall conclusion that can be drawn from the survey is that research efforts would be useful in the area of batteries and energy management. Battery technology that exhibits higher energy density and increased discharge cycles must be pursued. Technologies in the areas of monitoring and charging for the wheelchair application should be pursued. Advances in these areas would be greatly appreciated by the community

Reference

[1] C. Brubaker, "A Survey of Powered Wheelchair Problems and Features," *Proceedings of Wheelchair IV*, December, 1988, pp. 68-75, RESNA Press, Washington, DC.

Acknowledgements

Funding for this survey was provided by the University of Virginia Rehabilitation Engineering Center, Grant Number H133E80003-90, from the National Institute on Rehabilitation Research, U.S Department of Education. Copies of the report can obtained by writing the authors.

Address of Authors

UVa Rehabilitation Engineering Center
P. O. Box 3368, University Station
Charlottesville, VA 22903

STRUCTURAL RELIABILITY ASSESSMENT TECHNIQUES APPLIED TO TUBULAR WHEELCHAIR FRAMES

16.3

J.D. Baldwin and J.G. Thacker
University of Virginia Rehabilitation Engineering Center
Charlottesville, VA 22903

Introduction

The design of any engineering system is subject to uncertainty in establishing the response of the system to its specified inputs. There are idealizations in the governing equations and, perhaps most significantly, there are approximations in the value of the required input parameters. The most notable example of uncertainty in design parameters occurs when we address the issue of metal fatigue. In the current context, we speak of the uncertainty in the design of a wheelchair frame and discuss the techniques available for predicting the ability of the wheelchair frame to perform its intended function as a function of time. The fundamental conflict between the familiar *factor of safety* technique and more modern statistical techniques is illustrative of how the designer can make a more rational statement regarding the longevity of a structure.

Discussion

For many years, the standard method of guarding against structural failure consisted of making the best estimates of the maximum stress acting in the loaded structure and comparing them with a material property such as the yield strength. If the maximum stress did not exceed the yield strength, a factor of safety, defined as

$$F.S. = \frac{\sigma_{max}}{\sigma_y} \tag{1}$$

gave some indication of the conservatism of the design. Based on experience, the designer would determine whether the factor of safety was sufficient for peace of mind. If the factor of safety was deemed to be too small, the remedy might involve increasing the size of the critical structural member to reduce the stress, reduce the maximum load that would be allowed on the structure or select a structural material with a higher yield strength.

The factor of safety is really a factor of ignorance. Because we acknowledge (often tacitly) that we have imperfect knowledge of the environment where structures will be used, we provide for an additional margin to account for the uncertainty. It is this arbitrary nature of the factor of safety that makes its use in design inappropriate when one is attempting to make the best estimate possible of the survival potential of a structure. The factor of safety's shortcomings become particularly acute when the life of a structure acted upon by fluctuating loads is considered. Any attempt to rationally specify a fatigue factor of safety is impossible and such factors will be completely arbitrary.

This paper is not intended to be a comprehensive description of a fatigue design methodology based on statistical considerations. We will, however, describe some of the concepts necessary to implement such a design strategy including random process load models, perturbed parameter finite element analysis and statistical models for material properties.

Perturbed Finite Element Analyses

An important consideration in performing a fatigue calculation is the effect of static stresses in the structure. For a structure that vibrates about its static equilibrium point such as a wheelchair, the static stresses are due to the static load only. In this context, there will be a statistical variation of the static stresses experienced by a population of nominally identical wheelchairs due to variations in frame tube cross sectional dimensions and variations in the weight of the target occupant population. Computationally powerful finite element codes can be used to make estimates of the amount of variation in the static stress distribution in a wheelchair frame due to these uncertainties.

For purposes of this discussion, we will assume that the dominant factors driving the uncertainty in the wheelchair frame static stress distribution are occupant weight, frame tube inside and outside diameters and frame tube modulus of elasticity. If these four parameters are assumed to be random variables described by a Normal distribution, we can estimate their combined affect on the static stresses acting in the wheelchair frame in terms of the first-order Taylor series expansion [1]

$$\sigma_{SS} = \sqrt{\sum_{i=1}^{n}\left(\frac{\Delta SS}{\Delta x_i}\sigma_i\right)^2} \tag{2}$$

This relationship states that if we perturb one of the random parameters an amount Δx_i, holding the others at their mean values, calculate the difference in the static stress relative to the mean static stress (calculated with all parameters at their mean value) and multiply by the standard deviation of the perturbed parameter, we can add up the contributions of each random variable to estimate the standard deviation of the static stress. In order to calculate this value we need to perform $n+1$ finite element runs: one to establish the static stresses and one for each of the random parameters. This may seem like a great deal of time to spend calculating a statistic that has traditionally been neglected from structural analyses, but is in fact very easy to do once the finite element model has been debugged and verified. It is our experience that far more time is spent developing the original model than is spent making the perturbed value computational analyses.

As an example, the finite element model of a single cross brace power wheelchair frame is shown in Figure 1. This 179 node model required several days to construct and debug, but the five runs necessary to perform the calculation of Equation 2 were completed in about one hour with a PC-based finite element package. This is a good example of obtaining important statistical information about a structure with relatively little effort.

Wheelchair Dynamics as a Random Process

The occupant loads acting on a wheelchair can be treated rather easily as a random variable. The stresses in the frame due to the wheelchair's dynamic response to uneven surfaces are more difficult to characterize, and for this we will use the language of the theory of random processes. A random process can be described simplistically as the set of outcomes of a repeated experiment; the process is random if we are not able to predict the outcome of the experiment on any given occasion. A simple example of a random process is the results of several rolls of a fair die. We do not know beforehand which side of the die will land face up, thus the outcome of the experiment is not predictable except in a probabilistic sense, i.e. a random event.

A very important class of random processes is the stationary, narrow band Gaussian (or Normal) processes [2]. This process is the most tractable mathematically and appears to be a good approximation for a significant class of structural problems. The requirement that the process be stationary means that the random variable does not change its probabilistic content as a function time. The narrow band condition is met for structures having dominant vibration frequencies in a very narrow range, i.e. lightly damped, strongly resonant structures.

A well-known result of random process theory states that for a stationary, narrow-band Gaussian random process with a mean value of zero, the distribution of peaks of the random variable versus time function is given by the Rayleigh distribution, whose probability density is

$$f(S) = \frac{S}{\rho^2}\exp\left[-\frac{S^2}{2\rho^2}\right] \tag{3}$$

where the parameter ρ is a statistical measure of the random process called the *mean square spectral density*.

For the purposes of this discussion, we will assume that the dynamic stress S at any point in the wheelchair frame is adequately described by a stationary, narrow-band Gaussian random process and that the mean square spectral density and the dominant frequency of vibration have been experimentally determined.

Fatigue Life Curve

A very simple model of the response of a metal to fatigue loading is the stress-based S-N curve [3] which is described by the equation

$$S = \frac{A}{N^m} \tag{4}$$

where A and m are curve fit parameters. The S-N curve is defined between 10^3 cycles, where the stress is taken to be 0.9 times the material ultimate strength, and 10^6 cycles, where the stress is taken to be 0.5 times the material ultimate strength. The parameters A and m are chosen so that the S-N curve plots as a straight line in log-log coordinates. By making corrections to the curve at 10^6 cycles accounting for surface finish, component size, stress concentrations and load type, we can model approximately the fatigue response of a wheelchair frame.

The fatigue of metals has long been known to be very random in nature, showing far more scatter in the experimental data than could be explained by experimental uncertainty alone. In an attempt to re-introduce some of the random character of fatigue into the single-valued S-N curve, we can assume, as a first step, that the material ultimate strength is a random variable that approximately obeys the Normal distribution. Using the algebra of expectation [4], the equations relating A, m, and S_u can be randomized and a transformation of variables performed to yield the distributional parameters for A and m. Thus by incorporating the known statistical nature of the material ultimate strength in the model, the S-N curve can be restated as probabilistic relationship between the stresses acting in the wheelchair frame and the number of cycles of stress to failure.

Combined Model and the Reliability Calculation

The computational model for the reliability of the wheelchair frame is composed of the three elements described above: the estimate of the statistical variation of the mean stresses, stating the probability structure of the stress peaks as a Rayleigh distribution and using the statistical S-N curve. The detailed derivations of the resulting equations are provided in the literature ([5],[6]) and are merely summarized here. The probability density function for the number of cycles to failure is given by

$$f(N) = \frac{mN^{m-1}}{\sqrt{2\pi}\,\sigma_A K^m}\exp\left[-\frac{1}{2}\left(\frac{\left(\frac{N}{K}\right)^m - \mu_A}{\sigma_A}\right)^2\right] \tag{5}$$

where

$$K = \left[\frac{1}{\sqrt{2}\,\rho}\right]^{\frac{1}{m}} \frac{1.0}{\int_{S_e^2/2\rho^2}^{\infty} z^{x-1}\exp(-z)\,dz}$$

$$z = \frac{S^2}{2\rho^2} \qquad x = \frac{2+\frac{1}{m}}{2}$$

The parameters σ_A and μ_A are the mean and standard deviation, respectively of the distribution of the S-N curve parameter A; S_e is the fatigue-corrected endurance limit at 10^6 cycles [3].

These equations were derived by assuming that only A showed significant variation with the ultimate strength and that m could be taken as a constant.

We note that the reliability of the structure is defined as the probability that it has not failed at some future mission time. Using the probability density function for the number of cycles to failure, Equation 5, we state the reliability function as

$$R(N) = \int_N^{\infty} f(N')\,dN' \tag{6}$$

Thus, once the parameters of Equation 5 have been specified, Equation 6 can be integrated numerically to give the structural reliability (probability of survival) at any number of stress cycles.

It should be noted that the reliability calculated by Equation 6 applies to only one point in the structure. Although no method exists for assessing the reliability of a structural *system* using this fatigue analysis, we can employ this method easily to predict the reliability of the several points in the wheelchair frame that are deemed to be the most susceptible to fatigue failures and thus have some idea of which structural detail will control the frame lifetime. Due to the strongly random character of the fatigue process, no method has been developed to accurately predict the absolute value of the reliability of a structural detail. It is felt, however that the method outlined here provides a reasonable means of predicting the relative merits of competing structural designs with respect to reliability.

Conclusion

We have sketched the fundamental concepts of assessing the reliability of a wheelchair frame experiencing fatigue under random loading. Specifically, once the probability density function of number of cycles to failure is established, the reliability calculation is straightforward. The contrast between the probabilistic design philosophy and the factor of safety method should now be apparent. Whereas the factor of safety method makes a rather arbitrary statement of the margin between structural survival and failure, the probabilistic method uses estimates of the scatter inherent in the design parameters to establish a probability of survival. The factor of safety method ignores any statistical variations; probabilistic method makes use of the uncertainty and is therefore a more rational approach to the design of wheelchair frames.

Acknowledgement

Funding for this research was provided by the University of Virginia Rehabilitation Engineering Center under the NIDRR Grant Number H133E8003.

References

[1] Scarborough, J.B. Numerical Mathematical Analysis 5th Ed. Baltimore: The Johns Hopkins Press, 1962.

[2] Crandall, S.H. and Mark, W.D. Random Vibration in Mechanical Systems. New York: Academic Press, 1963.

[3] Juvinall, R.C. Engineering Considerations of Stress, Strain and Strength. New York: McGraw-Hill Book Company, 1967.

[4] Haugen, E.B. Probabilistic Mechanical Design. New York: John Wiley & Sons, 1981.

[5] Baldwin, J.D. Structural Reliability Analysis of Power Wheelchair Frames, Master of Science Thesis, University of Virginia, 1990.

[6] Baldwin, J.D., Thacker, J.G., & Baber, T.T. Estimation of Structural Reliability Under Random Fatigue Conditions, to be presented at the ASME Ninth Biennial Conference on Reliability, Stress Analysis and Failure Prevention, 1991.

J.D. Baldwin
University of Virginia Rehabilitation Engineering Center
Charlottesville, VA 22903

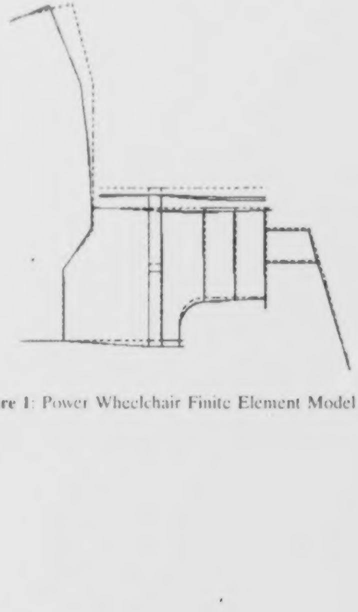


Figure 1: Power Wheelchair Finite Element Model

16.4

A Derivation of Turning Geometry and Turning Dynamics for Racing Wheelchairs

Rory A. Cooper, and Kimberly Watanabe
Rehabilitation Engineering Program and Assistive Device Center
Department of Electrical and Electronic Engineering
California State University, Sacramento

ABSTRACT

Turning geometry is important to the design and analysis of racing wheelchairs. Turning geometry plays an important role in the handling and stability of racing wheelchairs. It is also important from the perspective of efficiency, especially for track racing where much of the time is spent turning.This paper presents a theoretical analysis of turning geometry for three and four wheeled racing wheelchairs.The results of this analysis can be used to study wheelchair stability, and to reduce scuffing by the front wheels while turning.

Introduction

Three and four wheeled racing wheelchairs are commonly used by wheelchair racers. Both chairs have their relative advantages and disadvantages. Three wheeled chairs are generally lighter, and more responsive. Whereas four wheeled chairs are more stable.A growing number of studies are concerned with describing factors affecting racing wheelchair performance (Cooper, 1990). Most studies focus on the measurement of metabolic parameters and athlete classification, while a few focus on biomechanics and wheelchair design. Despite racing wheelchairs being quite popular among persons with mobility impairments little scientific effort has been applied to their design.Researchers at the University of Virginia Rehabilitation Engineering Center have investigated numerous aspects of standard wheelchairs (Brubaker, 1988). Recently a few studies have been published dealing primarily with racing wheelchair design (Cooper, 1990a,b, York & Kimura, 1987). This investigation focused on wheelchair turning geometry.

Research Question. Derive a relationship between steering angle and turning radius for racing wheelchairs, and develop the Ackerman steering geometry for racing wheelchairs.

Methods

For racing wheelchairs, steering is normally effected by changing the heading of the front wheels through the steering system (commonly a lever attached to the front fork). At the speeds travelled while wheelchair racing, there is a simple relationship between the direction of motion of the wheelchair and the steering lever angle, and the turning behavior mainly depends on the geometry of the steering linkage.

Ackerman Steering Geometry. A primary consideration in the design of steering geometry is minimum tire scrub during cornering. This requires that during turning all tires should be in pure rolling without lateral sliding. Thus all wheels should follow curved paths with radii originating from a common center, Figure 1.

The geometry describing the paths of each wheel about the common center establishes the desired relationship between the steering angle of the inside front wheel δ_i and of the outside front wheel δ_o (Wong, 1978). From Figure 1, it can be demonstrated that the steering angles δ_i and δ_o should satisfy equation (1).

$$\cot\delta_o - \cot\delta_i = B/L \qquad (1)$$

Where B := The track of the Wheelchair
L := The wheelbase of the Wheelchair.

Equation (1) can be derived graphically from Figure 1 as follows: Draw a line from the midpoint of the front axles M to the center on the inside rear wheel F. Next lay out the steering angle for the outside front wheel δ_o from the front axle. Line DO intersects line MF at Q. Connect point Q with the center of the inside front wheel C, then angle $\angle QCM$ is the Ackerman steering angle of the inside front wheel δ_i which satisfies equation (1). Refering to Figure 1,

$$\cot\delta_o = \frac{B/2 + e_2}{e_1} \qquad (2)$$

$$\cot\delta_i = \frac{B/2 - e_2}{e_1} \qquad (3)$$

and

$$\cot\delta_o - \cot\delta_i = \frac{2e_2}{e_1} \qquad (4)$$

Because triangle ΔMAQ, and triangle ΔMCF are similar,

$$\frac{e_1}{e_2} = \frac{B/2}{L} \qquad (5)$$

and

$$\cot\delta_o - \cot\delta_i = B/L \qquad (1)$$

Turning Radius as a Function of Steering Geometry. When evaluating the stability or performance of a racing wheelchair, the relationships between the steering angle, the heading angle (with respect to the center line of the road) and the turning radius are all important. A primary reason for this is that the pilot controls the steering angle and that the heading angle and turning radius are factors in stability analysis. For the derivation of the relationships between steering angle heading angle, and turning radius refer to Figure 2. The derivation is for a three wheeled racing wheelchair, the four wheeled case yields similar results.

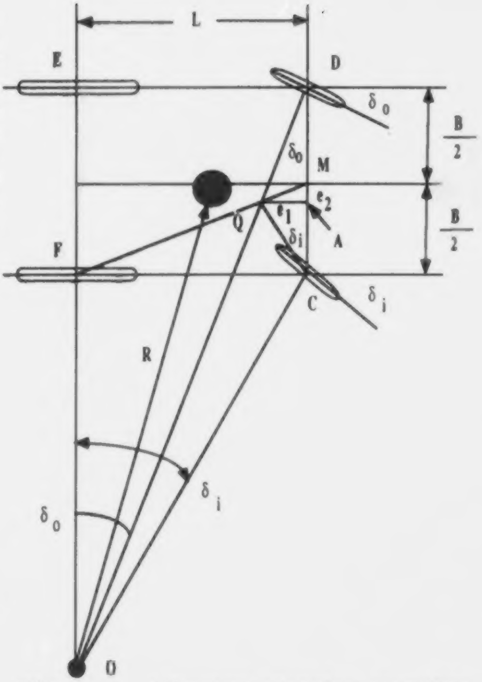


Figure 1. Ackerman steering geometry. (B = track, L = wheelbase, δ = steering angle)

Heading Angle as a Function of Steering Angle:

$$\tan\alpha = \frac{c}{a + B/2} \Rightarrow a + B/2 = \frac{c}{\tan\alpha} \qquad (6)$$

Where c := Distance from the rear axles along the centerline of the chair to the center of turning radius.

$$\tan\delta = \frac{L}{a + B/2} \qquad (7)$$

$$\tan\delta = \frac{L}{c}\tan\alpha \qquad (8)$$

Therefore

$$\alpha(\delta) = \tan^{-1}\left(\frac{c}{L}\tan\delta\right) \qquad (9)$$

Turning Radius as a Function of Steering Angle:

$$\sin\alpha = \frac{c}{R} \Rightarrow R(\alpha) = \frac{c}{\sin\alpha} \qquad (10)$$

Therefore

$$R(\delta) = \frac{c}{\sin\left[\tan^{-1}\left(\frac{c}{L}\tan\delta\right)\right]} \qquad (11)$$

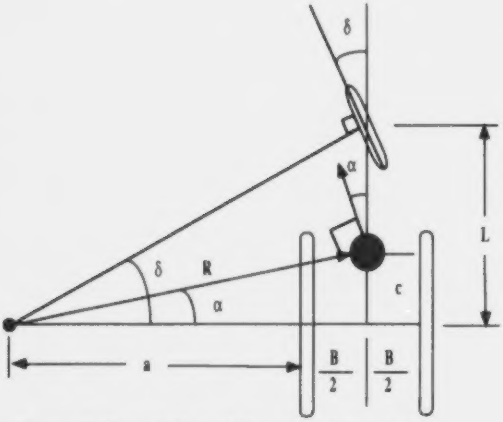


Figure 2. Description of the geometric relations between steering angle (δ), heading angle (α), and turning radius (R).

Results

The results show that if the steering angles of the front wheels δ_i and δ_o.satisfy equation (1), then by laying out the steering angles from the front axles, the intersection of the noncommon sides (Q) will lie on a straight line connecting the midpoint of the front axles and the center of the inside rear wheel. Equation (1) indicates that the relationship between the steering angles is nonlinear. Ackerman steering geometry is optimum in the sense that it minimizes scuffing while turning. The equations describing heading angle, and turning radius are functions of the racing wheelchair dimensions, and the steering angle. These results are important to the analysis of wheelchair stability and performance.Heading angle and turning radius are both nonlinearly dependent upon the heading angle.

Discussion

The relationships for Ackerman steering for racing wheelchairs can be used to evaluate steering geometries presently in use, and to redesign racing wheelchair steering geometry to minimize scuffing while turning. This may be especially important while track racing as nearly half of every race is spent turning. Perhaps performance could be improved and incidence of injury could be reduced through further study of turning geometry.

The relationships between steering angle, heading angle, and turning radius present tools to further pursue wheelchair stability from a human/machine control system perspective. The steering angle could be used as in input and the heading angle and turning radius would be outputs. Then the wheelchair/pilot system could be studied while performing various turning maneuvers. Both heading angle and turning radius are critical stability variables especially on irregular road surfaces.

Acknowledgements

Partial funding for research was provided by Rehabilitation Services Administration, U.S. Department of Education (Grant #H129E00005).

References

1.Cooper,R.A.: Wheelchair racing sports science: A review, Journal of Rehabilitation Research and Development, 27(3):295-312, 1990.

2.Brubaker,C.E.: Advances in wheelchair technology, IEEE Engineering in Medicine and Biology Magazine, 7(3):21-24, 1988.

3. Cooper, R.A.: The racing wheelchair, SOMA Engineering for the Human Body, 4:28-34, 1990.

4. Cooper, R.A.: Racing wheelchair roll stability while turning, Proceedings RESNA 13th Annual Conference, Washington, D.C., June, 65-66, 1990.

5. Wong J.Y.: Theory of Ground Vehicles, John Wiley & Sons, New York, 1978.

6. York S.L., & Kimura I.F.: An analysis of basic construction variables of racing wheelchairs used in the 1984 International Games for the Disabled, Research Quarterly for Exercise and Sport, 58(1):16-20, 1987.

Rory Cooper
Coordinator
Rehabilitation Engineering Program
Biomedical Engineering
California State University
Sacramento, California 95819-6019

OPTIMISING OF A CUSTOMISED SEATING SERVICE

Gilbert D. Logan & Peter J. Slattery
Royal Brisbane Hospital, Brisbane, Australia.

Abstract

Running a rehabilitation engineering centre providing customised seating and mobility in a large government-funded public teaching hospital is described. Experiences in various materials for seating such as Matrix Seating System and Foam-on-Ply are related. The service travels to country areas. Demand for services far exceeds present capacity to produce assistive devices. Optimising performance of the service to ensure best use of scarce resources has been explored, i.e. setting performance criteria on required outcomes of a client's customised seat and ensuring client assessment data is in a form usable for manufacture. Some pitfalls to avoid in setting up a service are related.

Background

A Rehabilitation Engineering Centre has been operating at Royal Children's Hospital for about ten years. The service is a small part of a large Department of Physical Sciences providing bioengineering and radiation physics services to a group of hospitals. The service commenced as a grant funded project and developed informally into a continuing service. The majority of clients of the centre have severe physical disability, often with associated low level intellectual functioning. Customised seating and mobility are the main requests for assistance. The service also undertakes tasks in design and manufacture of special prostheses and special aids for daily living. The majority of clients live in the heavily populated S.E. of the state. The centre travels to 3 provincial cities annually. Numerous other large population centres have no access to rehabilitation engineering services. One other agency provides similar services for people registered as suffering cerebral palsy. Few commercial services exist. Our centre can provide services to at best, 160 clients per year; far less than the demand.

Objective

A service which is understaffed for the work demand placed on it has to develop mechanisms to optimise performance. This paper relates our approach.

Method/Approach

Seat inserts are manufactured using conventional Foam-On-Ply, and the Matrix Seating System. We used the Matrix Seating System almost exclusively for a number of years and found it versatile and effective but not universally so. The level of technical skill to assemble it, frequent maintenance and the time expended to adjust it were impediments. Certainly Matrix sheet material was easily adjusted for growth and change of shape, however modification of the supporting exoskeleton was a major task, particularly for seating designed to accommodate severe deformity. Matrix use was often frustrated by problems such as institution staff putting the covers on upside down.

Lack of flexibility of the Matrix material compared to polyurethane foam meant that correct placement of the person in the seat was crucial to good seat performance. Matrix had advantages in making seating for hypotonic children and for hospital in-patients such as head injured and Guillain-Barre Syndrome children. Symmetrical seats could be made quickly and provided for frequent adjustment as the child's condition changed.

Foam-on-Ply is low technology but it works. It has advantages of using readily available, low cost materials and requires a minimum of equipment to work it. Complex contours can be achievable by building up thin sections. Covering foam seats is best done by an upholsterer. It is cost effective to send out items to be covered than to add to the burden of tasks. Small supportive frames used for small Matrix seats became a modular system for F-o-P as the frames could be pre-cut and assembled in a number of sizes to which F-o-P seat, backrest and headrest panels could be quickly mounted after shaping. This form of manufacture is quick and lends itself to adjustment during the fitting and at later assessments.

Many of our clients must wait for up to 9 months for the start of manufacture of their seating system. A constant problem was the difficulty in making use of information recorded at the initial client assessment at the manufacturing stage. We found that the type of information gathered or the form of recording was of little value when fitting the client with a seating system. Assessment data tended to have a medical connotation and was subjective and descriptive; the information of interest to the technical processes needed to be objective and analytical.

A major problem faced by us has been the establishing of criteria by which the efficacy of the seating system can be judged. Lack of some guidelines here leaves the door open for opportunists who are never satisfied, to receive extra attention to remedy a never-ending list of problems. Certainly some flexibility has to be exercised as seating of difficult cases involves trial and error. It is important to come to an agreement at the assessment stage of the desired outcome of the seating system for the client from say the therapist's point of view and what is practicable to achieve.

Discussion

Taking on one seating technology to the exclusion of others as a solution to problems such as long waiting lists for services or a means of dealing with difficult seating cases introduces risks. There is no guarantee of success with any seating system - failure is inherent in the nature of the problem. The initial enthusiasm of staff to take on a new technology as the answer to problems may give false indication of its success. We noticed in our use of the Matrix system that our enthusiasm did improve performance for a time and swelled output. At the same time the pool of work to be done also increased as people curious about the possible benefits of a new technology clambered to receive it. The new system did not really change the status quo. Once initial enthusiasm died down the same backlog re-appeared.

Probably more important than the technology is the position on a line between end-point limits of total customisation and mass production that a rehabilitation engineering service strikes as a trade-off between total client satisfaction and efficiency of an operation. Choosing the total customisation end means much time is spent solving the client's problem by trial and error with many attempts to achieve the optimum solution. The mass production end means that the client has to fit into something "off the shelf", so that "near enough is good enough". Few R.E.C.'s can afford the financial or time impositions of total customisation; R.E.C.'s should not be in the business of mass production. The balance point on the total customisation - mass production line must be chosen with limits in mind as to the standard of performance which the service can supply. Achieving the last 10% of performance may take 90% of the effort.

Some pitfalls encountered over time are:-

1) An R.E.C. should be formally set up and recognised by an agency which will support requests for funds and staff. Ad hoc arrangements create suffering and hardship when no one really owns you.

2) Taking on too much work with resultant long supply times leads to dissatisfaction of all parties and tarnished reputations.

3) Ensure clients and their family have realistic appreciation of what is practicable to achieve.

Gil Logan, Dept. Physical Sciences
North Brisbane Hospitals Board,
R.B.H. Post Office, Queensland
Australia. 4029.

A Comparison of Pulmonary Functions of Wheelchair Racers in their Racing and Standard Wheelchairs

Rory A. Cooper, Ph.D.
Rehabilitation Engineering Program and Assistive Device Center
California State University, Sacramento

ABSTRACT

Wheelchair racers often sit in their racing wheelchairs with their knees closer to their chests than in their standard wheelchairs. It was hypothesized that having their knees elevated may reduce pulmonary functions hindering racing performance. Eleven trained male paraplegic wheelchair racers performed SVC, FVC and MVV pulmonary function tests from their standard and race chairs. A 2-tailed paired t-test ($\alpha = 0.05$) was used to determine whether the subjects showed a significant difference in pulmonary functions for the two types of chairs.No significant differences were observed.

Introduction

Wheelchair racers often place their knees closer to their chests while in their racing wheelchairs than they do while sitting in their standard chairs (Ridgway et al, 1988) (Figure 1). By elevating their knees wheelchair racers gain several advantages. They are more stable because they can support their trunk with their legs when they lean forward at the end of their stroke. They have greater control of the wheelchair because the neurmuscularly uncontrollable portion of their body is brought in close to the portion of the body over which they have control and through the use of strapping they are bound together. Manueverability is also increased as the athlete's body mass is centered more tightly about the rear axles reducing rotational moment of inertia. However their may be some physiological reasons for not wanting to place the knees close to the chest. Pulmonary function may be decreased because the abdomen is compressed, and the diaphragm may be restricted. Blood flow and venous return may be restricted due to strapping and positioning. Temperature regulation may be reduced because of the restricted airflow over portions of the body which are neurologically intact.

A growing number of studies are concerned with describing factors affecting racing wheelchair performance (Cooper, 1990). Most studies focus on the measurement of metabolic parameters and athlete classification, while a few focus on biomechanics and wheelchair design. Burkett et al (1988) studied peripheral blood flow of wheelchair racers in their racing wheelchairs, and found some restriction of blood flow, but it was not statistically significant. Presently, there are no published reports on the affects of elevating the knees on pulmonary functions.

Research Question. For this investigation, it was hypothesized that elevating the knees may affect the pulmonary functions of trained paraplegic wheelchair racers with spinal cord injuries.

Methods

Subjects. Eleven male paraplegic wheelchair racers with spinal cord injuries gave informed consent and participated in this study. All of the athletes were well trained.Their best 10K times within a month of the tests ranged from 23 to 32 minutes with an average of 27 minutes. The average age of the subjects was 30.9 years, height was 173.8 centimeters, and weight was 66.0 kilograms (Table 1). All of the subjects were free from injury and illness at the time of the study.

Protocol. Each subject performed three slow vital capacity (SVC) tests, three forced vital capacity tests (FVC), and three maximal voluntary ventilation (MVV) tests while seated in their standard chair and again in their race chair.Therefore each subject performed eighteen pulmonary function tests. All of the tests were performed in the morning of the same day. The order of the pulmonary functions tests, and the order for the type of chair was randomized. However, for the convenience of the subjects, all of the pulmonary function tests for a given chair were performed before transferring into the subjects other chair.The spirometry was performed using a VACUMED 9 liter Dry Rolling Seal Spirometer, and VACUMED spirometry software. The spirometer was calibrated with a three liter syringe on the morning of each test.Forced expiratory volume (FEV-1), peak expiratory flow rate (PEFR), and tidal volume (TV) were automatically determined by the software from the FVC, SVC, and MVV tests.

Statistical Analysis. A two-tailed paired t-test was used to determine whether there was a statistically significant $(\alpha = 0.05)$ difference in the pulmonary functions for the different positions of the two types of chairs. The statistical analysis was performed on a Macintosh SE/30 computer using StatView software.Maximal values from each test (SVC,FVC,MVV) and chair (race,standard) were used in the statistical analysis.

Results

The results of each athletes pulmonary functions tests are presented in Table 2. The spirometry values listed are those which have been found to be some of the best indicators of pulmonary function (FVC, FEV-1, FEV-1/FVC, PEFR, SVC, TV, MVV).All of the mean spirometry values fall within normal ranges. The mean MVV values for the race chair (201.55±11.08) and for the standard chair (206.45±9.06) are an indication that the athletes are well trained.

The results of the statistical analysis indicate that there were no significant $(\alpha = 0.05)$ differences between the pulmonary function tests for the two chairs (Table 3). The statistical analysis showed that FVC and FEV-1 were least likely to be different for the two chairs (p=0.53 and p=0.64 respectively) and, PEFR and TV were most likely to be different for the two chairs (p=0.07 and p=0.08 respectively).

Discussion

The results of this study indicate that the body positions used by our subjects in their racing wheelchairs did not induce statistically significant changes in their pulmonary functions. This does not necessarily indicate that body position has no affect on pulmonary function, but it does indicate that body positions used by well-trained wheelchair racers do not affect pulmonary functions. This may be because athletes adapt their seating position to maximze their pulmonary, metabolic, and biomechanical efficiency (minimum entropy), albeit this may be a lengthy trial and error process.

Pulmonary functions may not be altered because with spinal cord injured subjects the muscles of the abdomen may not be innervated. Some athletes reported having better balance in their racing wheelchairs making it possible for them to use their functional musculature more effectively. Some athletes reported that they could sit upright in their racing chair at the beginning of the pulmonary function test and then lean forward against their knees to expell the air from the abdomen. This may account for the increase in PEFR and TV with racing wheelchairs.Thus compression of the abdomen due to body position may be

	FVC	FEV-1	FEV-1/FVC	PEFR	SVC	TV	MVV
Paired t value	-0.65	0.48	0.95	-2.03	-0.71	-1.93	1.05
Probability (2 - tail)	0.53	0.64	0.36	0.07	0.49	0.08	0.32

Table 3. Comparison of pulmonary functions of subjects in their racing wheelchairs and their standard wheelchairs.

compensated for by more effective exhalation.

References

1. Ridgway,M.,Pope,C.,&Wilkerson,J.: A kinematic analysis of 800-meter wheelchair racing techniques, Adapted Physical Activity Quarterly, 5:96-107, 1988.

2. Cooper,R.A.: Wheelchair racing sports science: A review, Journal of Rehabilitation Research and Development, 27(3):295-312, 1990.

3. Burkett,L.N.,Chisum,J.,Pierce,J., Pomeroy,K.,Fisher,J.,& Martin,M.: Blood flow and lactic acid levels in exercising paralyzed wheelchair bound individuals, Adapted Physical Activity Quarterly, 5:60-73, 1988.

Rory Cooper
Coordinator
Rehabilitation Engineering Program
Biomedical Engineering
California State University
Sacramento, California 95819-6019

	Height (cm)	Weight (kg)	Age (yrs)
Mean	173.8	66.0	30.9
Standard Deviation	10.4	6.4	6.1
Minimum	146.8	54.2	20
Maximum	186.7	74.85	41

Table 1. Description of the Subjects

Acknowledgements

Partial funding for research was provided by Capitol Campaign Fund, National Wheelchair Athletic Association, and United States Olympic Foundation.

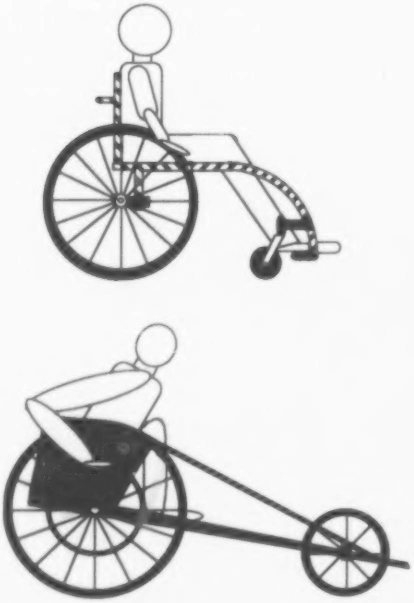


Figure 1 Illustration of athletes' positions in their wheelchairs.

Subject	FVC		FEV-1		FEV-1/FVC		PEFR		SVC		TV		MVV	
	race	standard	race	standard	race	standard	race	standard	race	standard	race	standard	race	standard
1	4.45	4.55	3.38	3.68	76	81	10.18	9.97	4.37	4.13	1.52	1.58	191	202
2	4.88	4.59	4.24	4.18	87	91	14.16	13.48	4.68	4.68	1.23	0.90	250	256
3	5.64	5.49	4.55	4.48	81	82	12.05	10.55	5.32	5.19	0.84	0.64	197	184
4	5.31	5.45	4.95	4.72	93	87	10.70	9.42	5.20	4.83	1.36	1.00	226	214
5	3.98	4.01	3.67	3.60	92	90	8.21	5.67	3.75	3.80	1.41	1.15	199	200
6	4.43	4.59	3.97	4.06	90	88	9.34	9.66	4.22	4.41	1.82	1.43	136	151
7	5.22	5.21	4.25	4.22	81	81	11.33	12.08	5.28	5.14	0.59	1.13	199	218
8	4.14	4.08	2.73	3.57	66	88	6.84	7.03	3.89	4.31	0.97	0.85	188	213
9	4.27	4.43	3.30	3.45	77	78	9.89	6.93	4.26	4.36	1.42	1.14	179	202
10	4.71	4.53	4.01	3.92	85	87	12.28	12.95	4.40	4.67	1.56	0.93	272	251
11	4.17	3.91	4.01	3.68	96	94	10.29	9.11	4.63	3.51	0.55	0.56	180	180
Mean	4.65	4.62	3.91	3.96	84.00	86.09	10.48	9.71	4.55	4.46	1.21	1.03	201.55	206.45
Std. Error	0.16	0.17	0.62	0.12	2.68	1.49	0.60	0.76	0.16	0.16	0.12	0.09	11.08	9.06

Table 2. Results of pulmonary function tests of wheelchair racers while in their standard wheelchairs and racing wheelchairs.

16.7

A SECOND-GENERATION JOYSTICK FOR PEOPLE DISABLED BY TREMOR

Jantje L. Hendriks, Michael J. Rosen, Norman L.J. Berube, Mindy L. Aisen
Newman Laboratory for Biomechanics and Human Rehabilitation
Mechanical Engineering Department
Massachusetts Institute of Technology

ABSTRACT

To improve the accuracy with which tremor-disabled people control powered wheelchairs and other assistive technology, a two-degree-of-freedom joystick has been built which incorporates viscous damping. Motivation for designing this device comes from positive experimental results obtained with an earlier version, and from the need to improve upon it in several respects. The design requirements include smaller size, interchangeable grip, and a fast-stop switch. Assembly of the second generation device is nearly complete at this writing. It apparently meets the stated requirements and experimental evaluation of its functional success will begin shortly.

PROBLEM DEFINITION

Tremor is the most common of involuntary movement disorders, and is characterized by rhythmic movement that occurs at rest or during activity. Tremor can be caused by benign familial conditions, degenerative neurological diseases such as Friedriech's Ataxia, Parkinson's Disease or Multiple Sclerosis, or from injury to the cerebellum or brainstem. It effects an estimated 800,000 people in the U.S.

One clinical classification is known as intention tremor. It occurs during performance of voluntary motor tasks and is reported to increase as the limb nears a target.

Many people affected by tremor are also wheelchair users and have great difficulty controlling the joystick of a powered wheelchair. Accurate control of wheelchair speed and direction becomes impossible due to the large amplitude oscillations produced by tremor.

DESIGN REQUIREMENTS FOR A DAMPED JOYSTICK

A now-standard approach to reducing the effect of tremor in wheelchair steering is electronic filtering, built into the wheelchair controller. There are several arguments, however, for applying a mechanical damping load at the joystick. The first is that the cosmetic improvement which results reducing extraneous hand movement may be as important as improved steering accuracy. Second, the amount of electronic filtering required for improved steering accuracy may make wheelchair dynamics unacceptably slow. Third, the interaction of tremor with the joystick dead zone and mechanical limits can introduce a dc error in control of the chair which may be difficult for the "driver" to compensate for. Finally, if the tremor mechanism involves reflex loop instability, the applied load may compensate the neural/mechanical dynamics in such a way that the tremor component of muscle force is reduced.

To obtain mechanical damping, a drag element moving through a fluid is coupled to the joystick handle. A prior RESNA presentation [1] described an earlier design for such an unit and presented positive experimented results on its effectiveness. A US patent has been awarded to MIT for the earlier design and commercial licensees are being pursued.

To develop a satisfactory damped joystick, several design considerations must be looked at carefully. The most important is the presence of differences among users. Along with the differences among tremors, other human factors introduce a wide range of variation.

To provide for individual differences in tremor, it must be possible to adjust the damping. This can be done by changing the size of the drag element, or changing the moment arm through which it acts.

Another difference among people concerns their preference and/or ability with respect to prehension. To satisfy the variety of user demands, several different grips should be available. This means that attention must be paid to the ease and speed with which grips may be interchanged.

The presence of damping also means that in emergency situations, the time necessary to bring the joystick back into center position to stop the wheelchair may be too long. To avoid accidents, a means for stopping the motor without delay must be added to the joystick. The fast-stop switch should be incorporated into the grip to avoid requiring the user to coordinate the use of his/her other hand or remove the wheelchair-operating hand from the joystick.

Further, the size of the joystick should be as similar as possible to the size of a conventional joystick. A larger one will not only impair the aesthetics of the wheelchair but also create clearance problems passing through doorways.

Finally, with respect to ease of manufacture, the parts should be as easy as possible to fabricate and assemble in quantity. Standard components should be employed where possible.

JOYSTICK DESIGN

This is the third design iteration of the MIT Damped Joystick, the second with adjustable damping. It is meant to retain approximately the same range of damping values as the earlier design while improving on it with respect to all the other design considerations listed above. The central operational principle, i.e. an extension of the shaft into a chamber of highly viscous fluid remains the same. The photographs at the end of the paper of the nearly-completed unit will serve to illustrate the descriptive text.

The redesigned drag element now moves in a basin filled with silicone grease having a viscosity of 2,500,000 centistokes. This is an increase by a factor of 2.5 relative to the earlier unit and permitted a reduction on the overall chamber from 4.5 to 3.5 in.

Changing the size of the drag element to change the damping, must not result in a change in the volume of the components in the basin because of the incompressibility of the fluid. As the damping is a function of the length and the diameter of the drag element, changing one of these results in a changing of the damping. The influence of the length is larger then the influence of the diameter, so a choice was made to provide adjustment by moving a cylinder up and down a shaft. The damping is the least when the bottom of the cylinder is flush with the shaft bottom, and increases as the cylinder is advanced axially. A hard stop limits the cylinder's travel. Moving the cylinder up and down is accomplished by rotating the inner shaft, which acts as a lead screw. To prevent rotation of the cylinder, it is keyed to an outer shaft which is fixed in the spherical-bearing and the grip. The inner shaft (lead screw) is connected to a dial-counter to give a reproducible setting. Locking the dial-counter, which is accessible only when the handle is removed, secures the drag element setting.

In conventional fashion, the shaft angles are transduced by means of two swing arms connected to potentiometers. The entire transducer unit is mounted on a lid, which seals the basin and supports the spherical-bearing.

The grip unit mates with a threaded disk. This disk is shrink-fitted to the outer shaft and supports the dial-counter. The grip unit is screwed onto the disk via a knurled locking ring.

To serve different grip needs, the decision was made to offer three kinds, a round knob, a T-handle, and a pistol grip (shown in the photographs). As stated above, each grip needs a built-in fast-stop switch. To make electrical contact between the grip unit and the telephone-style connector built into the joystick cap, a subminiature phone plug and jack are used. These contacts also orientate the grip. The lid, the swing arms and the potentiometers are covered with a PVC cap which has a round hole to accommodate shaft movement. A boot (not shown in the photographs) is placed between the cap and the disk to prevent the entrance of dirt and liquid and to prevent user contact with the electrical connectors and swing arms. The connector in the cap provides electrical connection between the wheelchair controller and the joystick.

FUTURE WORK

At this writing, plans have been completed for experimental evaluation of the new damped joystick. Testing procedures will include a video pursuit tracking task, a wheelchair driving test, and unconstrained functional driving trials.

The tracking task will present a rectangular video target and a cross-hair response cursor. The target moves randomly and the joystick user is asked to follow the target by moving the joystick. More details on this protocol are available in reference 1. Objective measures of tremor and voluntary tracking will be used to determine the extent of performance improvement as a function of damping level and for comparison to performance with undamped joysticks.

The driving test will require the subject to follow a curved path with a specified width (W) and a length (A). The subject will be asked to complete the path as quick as possible, without traveling outside its width. As the time(T) to complete this task will be modeled by Fitts law, i.e.

$$T = k \log_2[A/2W]$$

If a reasonable fit to the data is found, k will provide a measure of relative ease of use of the damped joystick at different damping settings and of undamped joysticks. Other mathematical representations will also be tried.

Also in development is a four-degree-of-freedom damped joystick. This joystick not only measures and damps the two tilt movements, but also rotation about the shaft axis and axial translation of the handle. Apart from use as assistive technology (i.e. control of powered stand-up wheelchairs and environmental control systems), it may also yield reverse spin-off to the aircraft industry. The engine-induced air-frame vibrations in helicopters in effect produce an externally-generated tremor in the pilot's hand. A 4 degree-of-freedom damped joystick might be used to avoid unstable coupling of this vibration to control inputs.

REFERENCES

1- Beringhause, S., Rosen M.J. & Huang S., Evaluation of a damped joystick for people disabled by intention tremor. RESNA 12th Annual Conference 1989.

ACKNOWLEDGEMENT

This work is supported by a grant from the Burke Rehabilitation center in White Plains, New York; and by NIDRR via the Harvard-MIT Rehabilitation Engineering Center. Support for Ms. Hendriks comes from NUFFIC and Genootschap "Noorthey".

ADDRESS

J.L. Hendriks MIT, 77 Massachusetts Avenue
Cambridge, MA 02139

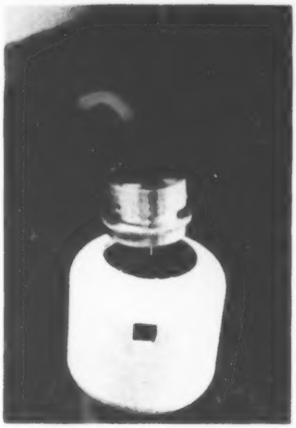


Photo 1 - Assembled Joystick.

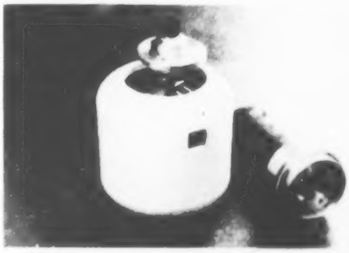


Photo 2 - Joystick with grip removed.

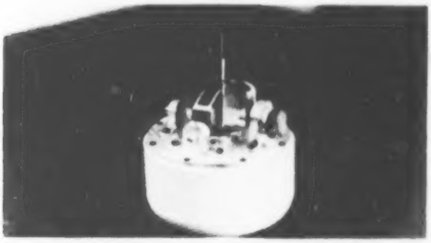


Photo 3 - View of transducer elements.

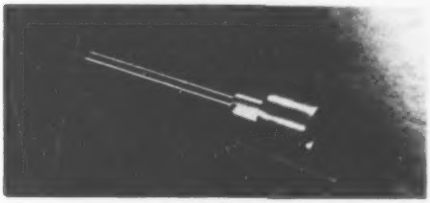


Photo 4 - Shaft and drag element.

SAFETY ASPECTS OF A USER CONTROL FOR A MOBILITY DEVICE

Larry Korba, G. Park
National Research Council of Canada, Autonomous Systems Laboratory
Ottawa, Ontario, Canada

Abstract

Controls that operate any device form the user's access point to the system. For the physically handicapped, these controls often must be placed for easy, speedy access. They must be reliable since a failure could produce effects ranging from annoyance to harm. This paper describes the development of safety features for a novel device designed as a control for a mobility device.

Background

Different types of mobility devices have varied requirements for their user interfaces. In some cases, off-the-shelf control switches can be used directly (e.g. joysticks). In others, special controls must be developed to accommodate features dictated by the needs of the mobility device and the user. A vehicle called the "five-wheel unicycle system" has been developed for use by those who find difficulty in walking or standing (1). It provides highly maneuverable locomotion for the user. "The basic design of the five-wheel unicycle comprises a circular, outer frame which has connected to it at least four stabilizing casters. One of the casters is fixed, acting as a 'rudder' for straight line travel. A turntable is connected to the outer frame by a circular ball bearing race. Centrally attached to the turntable is a motorized driving wheel, motor controller, battery and the seat. To provide steering for the vehicle, a steering hoop is connected to the outer frame by an adjustable vertical bar. The user steers the chair by turning his or her body to the desired direction of travel." (Quoted from 2.) A microcontroller was used to provide the motor controller functions (2). The speed of the wheelchair is controlled by pressing at any point along a flexible switch that is attached around the inside rim of the steering hoop. The original wheelchair used a single pole, single throw switch to control the speed of the wheelchair. Depressing the control ramped the motor speed to a preset maximum. To give the user control over vehicle speed, an analogue control device was developed. Initially, commercially available devices were evaluated. New controls were developed to meet the mechanical flexibility requirements of this application. A number of different types of materials were used to produce a flexible, variable resistance control. Conductive foam was used as the restive element of a control that could be easily applied to the inner curvature of the steering hoop. Although the control was quite sensitive to user touch, it suffered problems relating to calibration, degradation with age and complexity of construction. An additional problem was the lack of fail-safe operation. There was no way of differentiating between a switch failure (i.e., a non-zero resistance across its terminals) and a user command to turn the motor on.

As an alternative to the resistive type of control, an acoustic type was developed. The concept of this system is illustrated in figure 1. A rubber hose forms the acoustic path between a sound emitter and a microphone. The amount of sound that passes from emitter to microphone is determined by the quality of the acoustic pathway between the two devices (or in this case, the degree of compression of the rubber tube). Measuring the change in sound level at the output indicates the degree of tube compression.

The acoustic control system is quite flexible in its positioning (due to the flexibility of the connecting hose). A problem that presented itself during testing of the concept was the sensitivity of the device to external auditory noise. To rectify this problem, the microcontroller that is used for controlling the motor was also employed to implement a sampling system to minimize the effects of external sounds using a subtraction and filtering techniques (figure 2) (3).

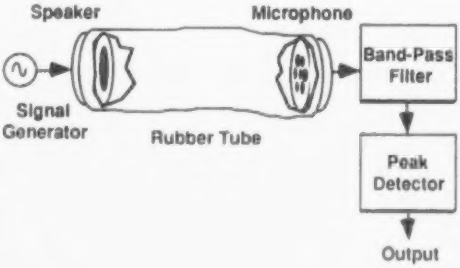


Figure 1. Acoustic switch concept..

The resulting system automatically adapts to changes in the tube length, diameter and placement. It has high noise immunity. Although the system performed adequately on the prototype, there still remained the very significant problem of lack of safety.

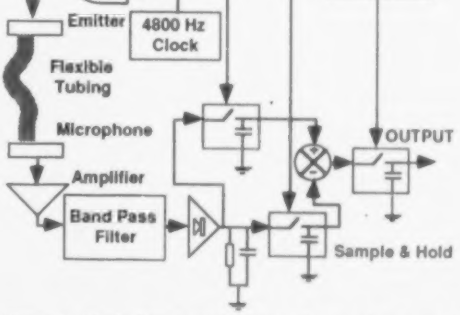


Figure 2. Block diagram representing the signal processing performed for the acoustic control.

Objective

By examining the control's response (without shunt, figure 5), it is clear that failure of the emitter, microphone, their associated circuitry or wiring (i.e., all defects that would cause zero detected sound at the microphone), would be interpreted by the system as a fully on command. Obviously when using this system to control the speed of a wheelchair, this is an unacceptable situation. A simple break in the wire connected to either the emitter or microphone would cause the wheelchair to move forward at full speed. Our objective then was to improve the performance of this control so that faults in its components or wiring would be recognized and the wheelchair would not operate.

Method

The situation here is somewhat analogous to using a normally closed switch to control the speed of the motor (figure 3). When the switch is closed, the motor is stopped, when it is open, the motor moves at full speed. Considering only the switch and its wiring, there are a number fault conditions that can produce one of two impedances at the connection to the controller (zero or infinity). At the input to the controller it is impossible to distinguish between a fault and regular operating conditions. To improve this situation, a resistor R can be connected directly across the switch connecting terminals. As shown in figure 4, there are now three possible impedances at the control input of the controller: zero, infinity or R. In normal operation, the impedance changes between zero (switch closed) and R (switch open). One possible error, a wire break, is indicated by an infinite impedance. In this scheme, although faults in the wiring to the switch can be detected, there is no direct way of detecting a short circuit in the wiring or the integrity of the switch.

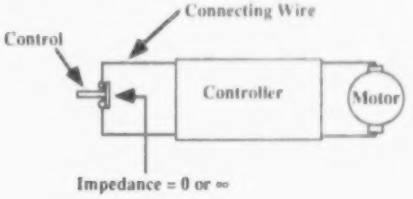
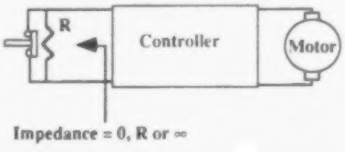


Figure 3. An analogous situation to the acoustic control is found when using a normally closed switch to control a motor. If the wire to the control breaks, the motor is always on.

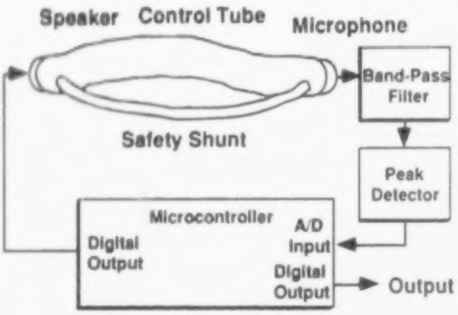


Impedance	Normal	Error Condition
0	Switch Off	Connecting wire short
R	Switch On	
∞	-	Wire Open

Figure 4. By adding a resistor R and a means for detecting the difference between three impedance levels, broken wires to the switch can be detected (Shorts or faulty switches cannot be detected).

In the case of the acoustic control, a similar principle can be applied by adding an extra acoustic path between the emitter and the microphone. Figure 5 illustrates the physical configuration. A second flexible tube of a smaller diameter than the control tube provides a second acoustic connection between the emitter and the microphone. The objective here is to provide a sound pathway so that under normal operation, the microphone will always receive some sound from the emitter. The acoustic shunt must be protected from compression during the control's normal use. For the five-wheel unicycle, the lumen of the metal steering hoop surrounding the user can be used as the pathway for this acoustic shunt. With this arrangement, a number of faults can be detected. The chart in figure 5 lists a number of faults and their measurable effects. The acoustic shunt affects the operation of the acoustic control by slightly narrowing the control's operating range. As shown in figure 6, the maximum sound level received by the microphone is lowered (no force condition) and the minimum sound level is now not zero (full force condition).

For the five-wheeled unicycle, a single chip microcontroller operates its single motor. The signal processing algorithm was implemented on this microcontroller to provide the basic acoustic control functions. To implement the test for control integrity in the software, whenever the control is read its setting is compared to a minimum threshold (1/2 of the Min value (figure 6), in this case 0.09 Volts), the control is not operational and an error message is indicated.



A/D Input	User Control	Error Condition
> Max	Control Off	-
<Max, >Min	Variable Control	-
<Min	-	Faulty Emitter or Microphone or Peak Detector or Amplifier or Tube or A/D

Figure 5. The acoustic control with an added acoustic shunt for fault detection. The table indicates conditions detectable by the microcontroller. (Refer to figure 6 for values of Max and Min)

Discussion and Conclusions

The acoustic control is a viable option as a control device. It offers a control that can be long, flexible tube. By using connecting tubes of different diameters and rigidity, a wide range of control pressure sensitivities can be accommodated. With the addition of the acoustic shunt, the microcontroller can detect faults in different elements of the control. Although some of the dynamic range of the control is lost due to the sound that is passed through the shunt, this sacrifice is vital for satisfactory use of the control with a mobility device. In the practical application of this safety measure, a fitting that attaches to the emitter and channels some of the sound to the safety shunt must be designed. No special fitting is required at the microphone end. As well as passing the sound through an additional external tube, another possible arrangement is a flattened, malleable (copper) tube within the lumen of the control tube. This would of course limit the flexibility of the acoustic control. Another possibility for improved safety design is provision of an electrical pathway between the transmitter and the receiver. This connection, however may be used only to ensure only the electrical connectivity between the controller and the emitter and microphone, not their operation.

Key to the development of this control device is the microcontroller. It provides the device with its automatic compensation for control tube size or positioning changes, self testing and fault-tolerant features. In this application, as in many consumer devices, a microcontroller is already used for other functions. The control function requires only a small portion of the microcontroller's computing facilities (in this case, less than 10 %). Considering the unique benefits of the control, the relatively minor additional hardware and software costs are well worthwhile.

REFERENCES

1. Roy, O.Z., Durie, N.D., Farley, R., Perkins, G., Tierney, K., and Skrypnyk, R., "Five-wheel unicycle system." Med. & Biol. Eng. & Comput., No. 23, 1985, pp. 593-596.

2. Korba, L., Park, G., Farley, R., Durie, N., Roy, O.Z. Development of a wheelchair controller: conversion to a microcontroller. Proceedings of the 13th Annual Conference of the Rehabilitation Engineering Society of North America, Washington, D.C. June 15-20, 1990, pp. 199-200.

3. Korba, L., Park, G., Farley, R., Roy, O.Z., Durie, N., "Highly flexible, analogue output control for use by the handicapped: the Acouswitch". Med. & Biol. Eng. & Comput., 1991. in press.

Larry Korba
Rm. 318a, Bldg. M-50, Montreal Road
National Research Council of Canada
Ottawa, Ontario, Canada K1A 0R6

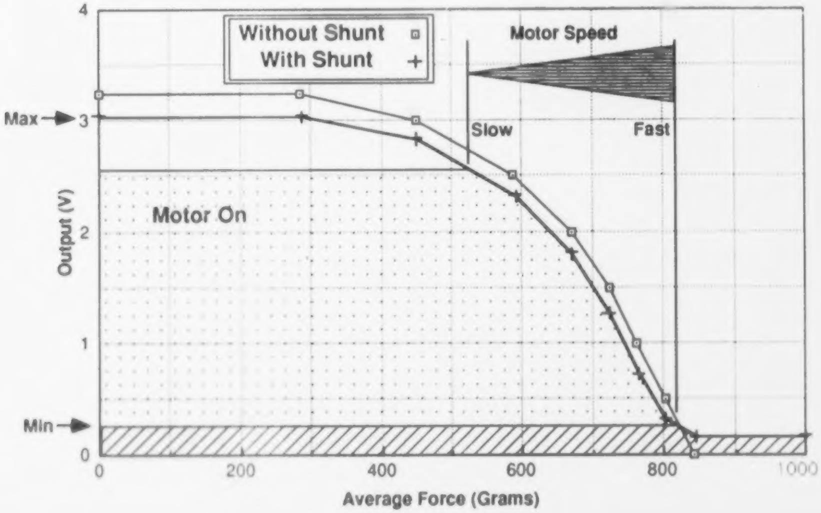


Figure 6. Response of the acoustic control with and without safety shunt. The force was exerted over a 1 cm. diameter area at different points along the tube to produce the average output in volts at the input to the A/D convertor of the microcontroller (vertical axis). The shunt's effect on the response of the control is a downward shift of its response and a plateau at the maximum force end (at 0.19 V.).

17.1

The Effect of Communication Aid Characteristics on the Interaction Skills of Nonspeaking Persons and Their Adult Speaking Partners

Sharon L. Glennen, Ph.D.
Kennedy Institute
Baltimore, Maryland USA

Abstract

The purpose of this study was to determine if features of high technology communication aids would significantly improve communicative interactions between nonspeaking persons and their adult speaking partners. The high technology communication aid features of (a) Both Printed and Speech Output, (b) Printed Output only, and (c) Speech Output only were compared against each other, and against (d) a simulated low technology communication aid with no output. The total number of communicative messages of the adult speaking partners and nonspeaking persons were measured to determine if there were any noticeable changes across the four communication aid conditions. In addition, mode of communication for the nonspeaking subjects was measured across all four conditions.

Background

Since 1978 when high technology communication aids were commercially available for the first time, nonspeaking persons have begun to use them with increasing frequency. Considering the popularity of high technology communication aids, relatively little is known about their effect on the interaction skills of nonspeaking persons. To date, the communicative interactions of nonspeaking persons using high technology communication aids have been analyzed in only four studies (Beukelman, et.al., 1984; Buzolich & Wiemann, 1988; Culp, 1982; and Harris, 1982). Between these four studies, a total of nine high technology communication aid users have been described. Based upon this limited data base, it is unknown whether high technology communication aids produce improved interactions between nonspeaking persons and their listeners when compared to low technology systems.

Research Questions

The purpose of this study was to determine whether some features of high technology communication aids significantly changed the communication skills of nonspeaking subjects and their adult speaking partners when compared to each other and to low technology communication aids. These features were (a) Both Printed and Spoken Output, (b) Printed Output Only, (c) Spoken Output Only, and (d) No Output/Low Technology communication aid simulation. Total number of communicative messages and mode of each message for both members of the interaction dyad was measured across the four communication aid conditions.

Research Method

The interaction skills of 12 nonspeaking subjects and their 12 adult speaking partners were measured across each of four communication aid conditions. Each of the 12 dyads interacted across all four conditions for a total of 48 separate interactions. The nonspeaking persons who participated in this study were 12 school age subjects who were proficient Touch Talker or Light Talker users. The subjects had been using their Touch Talker or Light Talker communication aids from 8 months, to 2 years, 1 month before participating in this study. At the time of this study, all of the communication aids were equipped with Echo II synthesizers and a liquid crystal display screen. Eight of the subjects accessed their communication aids through direct selection methods. Two subjects used row/column scanning, and the remaining two subjects used directed scanning. The nonspeaking subjects ranged in age from 8 years to 21 years. The mean age was 15 years, 1 month. Receptive vocabulary skills were measured using the Peabody Picture Vocabulary Test-Revised Form M (Dunn & Dunn, 1982). Age equivalents for the PPVT ranged from 7 years 6 months, to 18 years 6 months. The mean for the 12 nonspeaking subjects was 10 years 4 months.

The speaking partners were 12 familiar speaking adults who communicated regularly with the nonspeaking subjects at school but were not responsible for training the nonspeaking subjects to use their communication aids. The adult speaking partners ranged in age from 18 to 54 with a mean age of 34.25. With two exceptions, all of the adults were in occupations related to special education and rehabilitation. The speaking adults had known the nonspeaking subjects from a minimum of 1 month, to a maximum of 10 years. The mean was 2 years, 10 months.

For each of the four communication aid conditions the communication aid features of printed output or spoken output were turned on or disabled. The 12 subject dyads were then videotaped interacting together for 15 minutes while playing a modified barrier game.

The interactions were transcribed from videotape and analyzed for number of communicative messages. Both communication aid messages and other nonverbal messages of the nonspeaking subjects were transcribed and counted. Other modes consisted of eyegaze, head nods, gestures, and vocalizations among others. For communication aid messages, only complete messages were counted. Adult speaking partner verbal messages were also transcribed and totalled.

The nonspeaking subject and adult speaking partner dependent variables were analyzed separately across the four communication aid conditions by using repeated measures one-way analyses of variance. The four communication aid conditions were the main effect analyzed within each ANOVA.

Results

The total number of all communication aid messages plus other modality messages produced by the nonspeaking subjects was counted and compared across the four communication aid conditions. Table 1 lists the means and standard deviations for each of the four conditions. The nonspeaking subjects communicated most frequently in the No Output communication aid condition ($\underline{M}$ = 125.75), followed by Speech Output ($\underline{M}$ = 101.08), Printed Output ($\underline{M}$ = 92.25), and finally Both Printed and Speech Output ($\underline{M}$ = 89.58). These differences were found to be significant at a probability level of .000.

Total messages spoken by the adult speaking partners were also compared across the four communication aid conditions (See Table 2). The adults spoke least frequently in the Both Output communication aid condition (M = 131.08), followed by the Printed Output condition (M = 136.41), and Speech Output (M = 152.41). The adult speaking partners spoke an average of 192.33 times during the No Output communication aid condition. These differences were also found to be significant at a probability level of .000.

When mode of communication was analyzed the number of communication aid messages produced by the nonspeaking subjects ranged from a high mean of 13.58 in the No Output communication aid condition, to a low of 9.08 in the Both Outputs communication aid condition (See Table 3). The means for Speech Output and Printed Output fell between the other two communication aid conditions (Speech Output M = 12.58; Printed Output M = 10.00). These differences were not found to be of significance. Across all four communication aid conditions, the communication aid was used an average of less than 15% of the time.

Table 3 also shows frequency means for use of other modes of communication by the nonspeaking subjects. Use of other communication modes was highest in the No Output communication aid condition (M = 112.16), followed by Speech Output (M = 88.50), Printed Output (M = 82.41), and finally Both Outputs (M = 80.50). The results were significant with a probability of .000.

Discussion

Within a communicative interaction, the dominant communicator is the person who speaks most frequently. The dominant communicator tends to direct the interaction, and cause reactionary changes in the behavior of the more passive communicator. In examining the total messages of the adult speaking partners and the nonspeaking subjects, the adults clearly dominated all conversations. Across the four communication aid conditions, the adults spoke an average of 1.5 times as often as the nonspeaking subjects. These results matched the findings of previous studies which found that adult speaking partners dominated conversational interactions with nonspeaking persons (Light, Collier, and Parnes, 1985).

The adult speaking partners dominated the interactions by talking more frequently when the communication aid was simulating a low technology communication aid with no output. The nonspeaking subjects responded by communicating more frequently in this mode. A separate analysis of discourse functions and communicative intent which is not reported in this paper, found that the increase in adult messages was due to a significant increase in the use of requests in the No Output condition (Glennen, 1989). These were usually yes/no questions. The nonspeaking subject's increase in communication under this condition consisted of responses to these questions. Most of these responses were made through other modes of communication such as head nods, vocalizations, or gestures.

As the communication aid gave more intelligible or readable output, the adult speaking partners relinquished some of their conversational control over the nonspeaking subjects. This resulted in an overall reduction in total number of messages. The nonspeaking subjects reduced their messages by decreasing their use of other modes of communication. Use of the communication aid which was used most frequently to initiate new topics of conversation remained stable across all four conditions.

In summary, the communication aid effected interactions between nonspeaking subjects and their adult speaking partners. The adult speaking partners dominated the interactions more when the communication aid had less intelligible output. The adults were less controlling when the communication aid had synthesized speech output. This was followed by communication aids with printed output. The adults controlled the interactions least when communication aids were used with both speech and printed output. The nonspeaking subjects also changed their interaction skills across the four communication aid conditions. However, their changes tended to be in reaction to the adult speaking partner's changing interaction styles.

Acknowledgements

This paper was completed as part of the author's doctoral dissertation submitted to The Pennsylvania State University. The author would like to thank the Pennsylvania Assistive Device Center, Minspeak Incorporated, Prentke Romich Company, and the Maryland Rehabilitation Center for their assistance with this project.

References

Beukelman, D., Yorkston, K., Poblete, M., & Narranjo, C. (1984). Frequency of word occurrence in communication samples produced by adult communication aid users. Journal of Speech and Hearing Disorders, 49, 360 - 367.

Buzolich, M., & Wiemann, J. (1988). Turn-taking in atypical conversations: The case of the speaker/augmentated communicator dyad. Journal of Speech and Hearing Research, 31, 3 - 18.

Culp, D. (1982). Communicative interactions: Nonspeaking children using augmentative systems and their mothers. Paper presented at The American Speech Language Hearing Association annual convention, Toronto, Canada.

Glennen, S. (1989). The effect of communication aid characteristics on the interaction skills of nonspeaking persons and their adult speaking partners. Unpublished doctoral dissertation, The Pennsylvania State University, State College, PA.

Harris, D. (1982). Communicative interaction processes involving nonvocal physically handicapped children. Topics in Language Disorders, 2, 21 - 37.

Light, J., Collier, B., & Parnes, P. (1985). Communicative interaction between young nonspeaking physically disabled children and their primary caregivers: Part I, discourse patterns. Augmentative and Alternative Communication, 1, 74 - 83.

Table 1
Nonspeaking Subject Mean Total Messages

		Communication Aid Conditions					
		Both	Print	Speech	None	*F*	*p*
Total Messages	*M*	89.58	92.25	101.08	125.75	14.32	.000*
	SD	44.31	34.21	45.96	47.46		

Table 2
Adult Speaking Partner Mean Total Messages

		Communication Aid Conditions					
		Both	Print	Speech	None	*F*	*p*
Total Messages	*M*	131.08	136.41	152.41	192.33	33.00	.000*
	SD	73.44	56.69	75.31	71.84		

Table 3

Nonspeaking Subject Mode of Communication

		Communication Aid Conditions					
Mode		Both	Print	Speech	None	*F*	*p*
Total CommAid Messages	*M*	9.08	10.00	12.58	13.58	2.70	.062
	SD	4.01	4.08	6.55	7.12		
Total Other Messages	*M*	80.50	82.41	88.50	112.16	11.02	.000*
	SD	45.90	36.28	47.17	48.49		

Author Address

Sharon Glennen, Ph.D.
Department of Communication Sciences & Disorders
Kennedy Institute
707 N. Broadway
Baltimore, MD 21205

Age-Related Differences in Interface Control in Normally Developing Children

Cynthia J. Cress, Greta J. French
Trace R&D Center, University of Wisconsin-Madison
JoAnn P. Tew
Good Samaritan Hospital, Baltimore, Maryland

Abstract

For nondisabled adults, most standard computer interfaces are quickly learned and require little focused attention for successful use. For young children and persons with cognitive disabilities, procedural and cognitive requirements of the interface may make the interface difficult to use or even impossible to learn. In this study, 29 nondisabled children (37-60 months) used five different standard computer interfaces in four types of tasks: basic interface control, interface training, and two sorting tasks (involving additional decisions for successful interface control). Results indicate that children across all ages were able to achieve equivalent proficiencies with the interfaces, but that younger children were more frequently unable to learn interface operation, even given knowledge of the task and minimal motor prerequisites. Some of the sources of task difficulties across ages are described.

Background

Access to computers and electronic communication aids requires successful operation of an interface. For children with multiple disabilities, considerable assessment time is required to minimize the physical and sensory load of the interface selected. Minimizing cognitive load is particularly difficult, since limited information is available either on the relative complexity of interfaces or the cognitive skills required for their use. Human factors research has established that adults vary in the efficiency of control across interfaces, and that some of this variation is related to cognitive [dissonance] between the interface and task (Card, English, & Burr, 1978; Karat, McDonald & Anderson, 1985). However, since adults vary little in the cognitive skills required by the interfaces themselves (Cress & Tew, 1990), it is necessary to study persons who are still developing these cognitive skills in order to determine the threshold and relative impact of cognitive load on overall performance. Evaluation of learning methods and error patterns are particularly important when considering application to persons with cognitive disabilities, to match unique subject skills to interface requirements.

While children with cognitive skills functioning at 18-24 months can use single switches to operate computer tasks (Brinker & Lewis, 1982; Behrmann & Lahm, 1983; Rosenberg & Robinson, 1987), ability to operate more complex interfaces develops with increasing cognitive and motor skills. Chapman, Dollaghan, Kenworth, & Miller (1983) found that children as young as 2 years of age were able to select items with a touchscreen before any other interfaces, although they could not yet move the objects selected. Olsen (in preparation) found that children did not successfully use a mouse to move or draw shapes on a display until they were able to coordinate three separate control functions (click, hold and drag), which tended to occur around four years of age. Ratcliff (1987) found that students as old as 12 years were significantly less accurate at a motorically simple technique (single switch scanning) than a more complex action (direct lightpen selection) when indicating choices in a complex search task, which was attributed to the cognitive load involved in planning and waiting for a scanning technique. By comparing children's development of interface operation across tasks, it will be possible to identify some of the cognitive skills and learning experiences necessary to acquire adequate interface proficiency.

Research Questions

1. Which of the interfaces studied are fastest and easiest to learn for young children on object movement tasks?
2. How does skill at interface use differ between ages?
3. What types of learning styles and error patterns were exhibited by children?

Method

Subjects

Subjects were 29 normally developing children between the ages of 3-1 and 5-0 (mean age 3-11). Evidence of normal development included parent and teacher report of no known cognitive, motor, or sensory deficits, performance on the Bracken school readiness score (mental age equivalence) no greater than one standard deviation below the mean for their chronological age, and demonstration of task-specific cognitive skills by passing 10/10 on a paper version of computer tasks. Other descriptive measures included formal and informal assessments of: spatial relation skills, visual discrimination and pattern analysis skills, perceptual/motor problem solving skills, motor skills, Piagetian development, and computer experience.

Equipment

Computer tasks were presented using SuperCard on a MacIntosh FX with a color monitor. Interfaces were selected both for compatibility with this system and relative frequency in educational computing applications. The five interface modalities were as follows: a single button mouse (set at 1:1 movement ratio), a MouseTouch touchscreen, a TurboMouse trackball with separately programmed locking and nonlocking buttons, and the numberpad of an Apple extended keyboard with 8 cursor arrows on the keys 1-9 (excluding the 5 key) and with an opaque sheet covering the remaining keys. The cursor keys were programmed in nonrepeating mode, so that each keystroke indicated a standard distance moved. Except for the cursor keys, position of the screen cursor was continuous across trials, such that the cursor was activated for each trial from the last resting position.

Procedure
Subjects used each of the five interface modalities (in random order) to pick up, drag, and drop a pictured screen object in four different tasks. First, subjects were given two demonstrations and asked to try to deduce interface control for moving a pictured object between two screen locations without further explanation. Criterion for passing this screening task was at least 7/10 correct, and trial block was discontinued after four failures. If subjects failed the first computer screener, a training hierarchy was provided on a similar movement task, with successively more specific cues on interface operation until either end of hierarchy or success (3 successful trials by child independent of help). Screener was repeated after successful training, with same passing criterion. If successful on first or second screeners, the children completed two- and four-part sorting tasks (both at 8/12 passing criterion). Trials included both within-reinforcers, with animation and sound of pictured object at correct placement, and between-trial reinforcers, with gradual uncovering of an unrelated picture "puzzle" with each completed trial (regardless of success).

Data Collection
Quantitative data included computer recording of number of correct trials, number of object pickups and unsuccessful clicks, and amount of time required for each stage of interface operation. Qualitative data recorded by experimenter online included an eight-point coding score for precision of each subject response, number and type of each training cue provided, and subjective notes about procedural styles and errors of subjects. The data cells (task by interface) contain missing data, due to either technical recording failure or subject dropout.

Results
Figure 1 shows the average total times across subjects for each of the five interfaces by task, as well as the range of subject performance (the trainer and second screener are not included here because of different measurement criteria). The highest and lowest scores were dropped from the averages to minimize data skewing. The same relative order of interface speed was maintained across tasks, with touchscreen fastest and keyboard slowest, except for the mouse on the screener, which was the slowest over all tasks. Speed improved for all interfaces between the screener and two-part, but only slightly in the four-part sorting task. Ranges decreased with experience in tasks, but at least some children grew slightly less efficient between two- and four-part tasks.

Table 1 shows number of failures by interface, as another metric of relative difficulty of interface use. In this analysis, the locking trackball was the most consistently failed interface across tasks, followed by the mouse and keyboard. Note that all subjects who failed the first screener were given the trainer and as many further tasks as they could complete successfully. Thus, any failures beyond the first screener were either failure to learn or breakdown in subject ability to operate the interface.

Figure 1
Children's Average Time to Complete Three Tasks for Five Interfaces

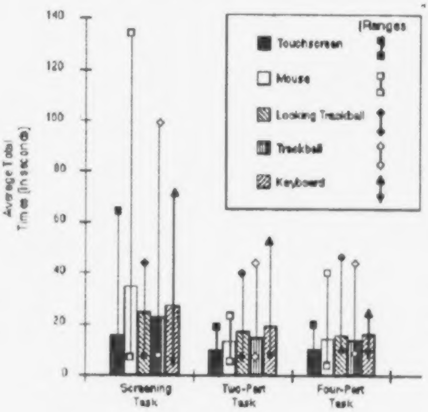


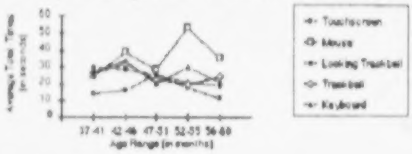
Table 1

Number of Trial Blocks Failed for Each Task by Interface

Interfaces	S(1)	T	S(2)	2P	4P*
Mouse	11	3	1	0	0
Locking Trackball	21	3	3	3	0
Trackball	9	0	0	1	0
Keyboard	11	0	1	3	1
Total failures	**58**	7	5	7	1

* S(1) = Screening 1
T = Training
S(2) = Screening 2
2P = Two-Part Task
4P = Four-Part Task

Figure 2
Age-Related Differences in Speed of Operation for Screen Task



In Figure 2, subject average times on each interface are plotted by age groups for the screening task. While subjects show variability in performance across ages, no consistent increase or decrease in scores is evident for any of the interfaces. For the two- and four-part tasks, the variability becomes minimal, with virtually flat graphs of interface speed across ages. However, Table

2 shows distinct qualitative differences in performance across ages, where children below 48 months (four years) more frequently failed to acquire necessary skills to complete training and/or sorting tasks than older children, although children from both groups failed initial screeners across all interfaces.

Table 2

Number of Trial Blocks Failed for Each Task by Age Groups

Age Ranges (months)	S(1)	T	S(2)	2P	4P*
37-41	12	2	2	1	0
42-46	25	3	3	1	1
47-51	12	2	0	2	0
52-55	4	0	0	1	0
56-60	5	0	0	2	0
Total failures	**58**	**7**	**5**	**7**	**1**

* S(1) = Screening 1
T = Training
S(2) = Screening 2
2P = Two-Part Task
4P = Four-Part Task

Discussion

The relative order of interface proficiency across children is comparable to that recorded for adults on the same tasks, except that the touchscreen is consistently faster than the mouse for the children tested (Cress, French, & Tew, in submission). One explanation for this difference is the delay that most children exhibited between pickup and movement of the target object while searching for the goal area, whereas adults performed this as a more continuous activity. The uniformity of relative speeds at least partially reflects characteristics inherent to the interface operation (Card, English, & Burr, 1978), such as a minimum number of keystrokes necessary to move an object to a desired location. However, only the fastest of the children's speeds approached the average for computer-experienced adults, suggesting delays resulting from the children's skills rather than the interfaces' characteristics.

Children across all age groups were able to use the interfaces with equivalent proficiencies, if they were able to use the interfaces at all. All children passed an informal motor screener that mimicked the movements necessary for interface operation. Thus, age-related development of movement precision is not a complete explanation for variation in performance. Common reasons for the training failures of the young children included: forgetting the sequence of interface operation, failure to self-correct inappropriate interface activities (such as moving the object off screen), interference between operation of different interfaces (e.g. trying to use the mouse button like a keypress), or deterioration or incomplete grasp of method for interface operation (e.g. inserting "superstitious" activities to make the interface work). Conversely, older children tended to fail due to task fatigue, decrease in motivation/attention, or a tendency to play with the object or its placement. Nearly all of the children, and many of the adults tested, began to experiment with the limits of the program and interface operation as soon as they were consistently successful with the interface. Thus, some of the trials scored as "failures" were apparently self-directed opportunities for improving interface skills and understanding. Further profiling of individual change in skill over time and with different kinds of training is necessary to predict long-term learning and performance with computer interfaces.

References

Behrmann, M. & Lahm, L. (1983) Critical learning: Multiply handicapped babies get on-line. In M. Behrmann & L. Lahm (eds.), *Proceedings of the National Conference on the Use of Microcomputers in Special Education.* Hartford, CT: ERIC.

Brinker, R.P. (1984) The microcomputer as perceptual tool: Searching for systematic learning strategies with handicapped infants. In R.E. Bennett and C.A. Maker (Eds.), *Microcomputers and Exceptional Children.* New York: Haworth Press.

Card, S.K., English, W.K., & Burr, B.J. (1986) Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics, 21*, 601-613.

Chapman, R.S., Dollaghan, C., Kenworthy, O.T., and Miller, J.F. (1983) Microcomputer testing and teaching of verb meaning: What's easy and what's hard? In A.C. Wilkinson (Ed.) *Classroom Computers and Cognitive Science.* New York: Associated Press.

Cress, C. & Tew, J. (1990). Cognitive skills associated with the operation of various computer interfaces. *Proceedings of the RESNA 13th Annual Conference*, pp. 251-252. Washington, D.C.: RESNA.

Cress, C., French, G., & Tew, J. (in submission). Patterns and individual variation in standard computer interface use in object movement tasks.

Karat, J., McDonald, J.E., Anderson, M. (1985) A comparison of selection techniques: Touch panel, mouse, and keyboard. IN B. Shackel (ed.) *Human-Computer Interaction - INTERACT '84*, Elsevier Science Publishers B.V.: North Holland.

Olsen, J. (in progress) Children's computer drawings as indications of perceptual and cognitive development. Unpublished manuscript, University of Wisconsin - Madison.

Ratcliff, A.E. (1987) A comparison of two message selection techniques used in augmentative communication systems by normal children with differing cognitive styles. Ph.D. Thesis, University of Wisconsin - Madison.

Rosenberg, S.A., & Robinson, C.C. (1987) Sensorimotor correlates of performance on a switch task by pupils with multiple handicaps. Unpublished manuscript. Omaha, Nebraska: University of Nebraska Medical Center.

Acknowledgements

Support for this work has been provided in part by Grant #H133E80021 from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education.

Cynthia J. Cress
Trace R&D Center, S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

Relationship of Communication Speed and Rate to the Perceived Communicative Competence of High School AAC Users

Kathleen A. Kangas
Idaho State University, Pocatello, ID

ABSTRACT

This study investigated the relationship between rate and speed of communication and the students' competence as perceived by school staff. Twenty-five high school aged students who use electronic communication devices were video-taped. School staff were asked to provide ratings of the students' overall communicative competence. Correlation techniques revealed that rate and speed measures were not significantly related to perceived competence. Descriptive measures of rate and speed of communication are presented, and other variables which appeared to influence the competence are discussed.

BACKGROUND

Studies of the communicative interactions of individuals using augmentative and alternative communication (AAC) have focused increased attention on the actual use of AAC in natural settings. In general, these studies have found AAC users to be more passive, slower, less directive, and less active in the communication interchange than their nondisabled partners (1,2).

One critical limitation of the interaction research to date has been the failure to address the issue of communicative competence (2,3). Research has been directed to describing the components of the interaction (4), without investigating the impact of these components on the effectiveness of the communication. And so, although we have descriptions of specific aspects of communication, our understanding remains limited with respect to how these components affect the ability of AAC users to function in various settings (2,3,5,6). One step in determining how to enhance competence, is to determine the contribution of various components or behaviors to the overall success of the individual.

Temporal characteristics of communication (e.g., latency, rate, and efficiency) are a consistent concern of clinicians and educators and of the designers of communication aids (7,8,9). Although the speed of communication is generally recommended as a significant issue in the selection of AAC approaches for an individual, there are few data to assist the clinician in determining what is a reasonable rate of communication to expect from a user of an electronic communication aid. Nor is there information which answers what rate of communication might be deemed successful in various natural communicative settings. This leaves clinicians and educators with little information to guide their determination of the importance of establishing improved communication rate relative to the importance of improving other communication skills.

RESEARCH QUESTIONS

The purposes of this study were (a) to describe the temporal characteristics of the communication of students using AAC devices in conversational situations and in group instructional activities, and (b) to determine the relationship between the temporal characteristics of the students' communication and the competence of their communication as perceived by special education staff. The Communicative Competence Rating Scale (CCRS) was developed to assess the perceived communicative competence of the subjects.

METHODS

Subjects were 19 junior high and high school aged students with severe communication impairments (in most cases caused by congenital physical disabilities) who had utilized electronic communication devices for at least nine months. Communication rate and speed were measured from videotapes of each student participating in a conversation with a familiar school staff person, and nine students were videotaped in a group instructional activity. Perceived communicative competence for each student was evaluated as the mean rating assigned by three special education staff members who were familiar with the student. Ratings were based on the 20-item CCRS developed for this study.

RESULTS

Communicative Competence

The total score on the CCRS was obtained by adding the ratings for the 20 items, with a range of possible scores from 20 to 100. The range of obtained scores was from 29 to 91.6, with a mean score of 65.66. For each student, three scores were obtained from ratings given by different staff members, and a mean competency score was computed. The range of mean scores was from 41.5 to 87.2. The mean score for each student was taken as the best single estimate of the student's overall communicative competence, and this is the score which was used in the correlation analysis reported below.

Speed and Rate

Several measures of speed and rate were based on the videotaped communication samples. One-to-one conversational samples for all 19 students were analyzed, and data from group instructional activities were analyzed for 9 students. Only messages for which the student used the VOCA were included. Only rate in words per minute (wpm) is reported here.

Rate was computed by dividing the number of words in each utterance by the time in seconds from when the student began to access the device until the message was completed. The rate was multiplied by 60, so that the resulting rate could be discussed as wpm. This does, however, have the effect of multiplying any error of measurement. In the conversational setting, mean rates in wpm for each student ranged from 38.71 to 3.12 wpm, with a group average of the mean rates of 14.085 wpm. In the group situation, the rates were quite similar. The individual mean rates ranged from 38.42 to 2.50 wpm, with a group average of 14.373 wpm.

Correlational Analysis

Means of the measures of speed and rate of communication and the mean competency scores from the CCRS were submitted to correlational analysis. Few of the correlations reached statistical significance, however, this is due at least in part to the small sample size. The direction of the trends may be meaningful for those correlations which approach significance.

The correlation between wpm and communicative competence in the conversational situation was near 0 ($r = -.098$). In the group activity, there was a nonsignificant trend in the data with $r = .300$, suggesting that rate in the group activity might be more indicative of overall perceived competence.

One of the specific measures of speed was access time, which was the time in which the student was engaged in activating the communication device. In the conversational setting, the correlation between access time and competence was $r = .423$, which approaches statistical significance ($p < .07$). The unexpected positive direction of this correlation suggests that students who are slower to access their devices (i.e., those with longer access times) are perceived as more competent. One possible explanation for this result was that the slower communicators were taking a longer time because they were constructing longer messages, and the longer messages contributed to a perception of competence.

DISCUSSION

Descriptive data from this study underscore concerns for speed and rate of communication when AAC communication is compared to average speaking rates. This highlights the challenges faced by the students and staff members when AAC users are included in classrooms with peers who use speech to communicate.

In the school settings studied, rate and speed of communication did not significantly affect the judgements of staff members regarding the overall communicative competence of students using AAC. It appeared that other variables, such as the general responsiveness of the students and their ability to communicate a wide range of pragmatic functions were more influential in the perceived competence. Subsequent studies might incorporate use of the same methodology to describe additional characteristics of communication and to investigate the communicative competence of individuals in other natural settings.

ACKNOWLEDGEMENTS

This paper is based on the author's Doctoral Dissertation at Purdue University, West Lafayette, IN. The project was supported in part by the Prentke Romich AAC Fellowship and by grants No. HO23B90015 and HO29D90094 from the U.S. Dept. of Education, Office of Special Education and Rehabilitation Services; however, no endorsement or approval by the supporting agencies should be inferred.

REFERENCES

1. Kraat, A.W. (1985). Communication interaction between aided and natural speakers: An IPCAS study report. Toronto, Canada: Canadian Rehabilitation Council for the Disabled.
2. Light, J. (1988). Interaction involving individuals using augmentative and alternative communication systems: State of the art and future directions. AAC, 4, 66-82.
3. Light, J. (1989). Toward a definition of communicative competence for individuals using augmentative and alternative communication systems. AAC, 5, 137-144.
4. Mathy-Laikko, P., & Yoder, D.E. (1986). Future needs and directions in augmentative communication. In S.W. Blackstone (Ed.), Augmentative Communication: An Introduction, (471-494). Rockville, MD: ASHA.
5. Calculator, S.N. (1988). Evaluating the effectiveness of AAC programs for persons with severe handicaps. AAC, 4, 177-179.
6. Zangari, C., Kangas, K.A., & Lloyd, L.L. (1988). Augmentative and alternative communication: A field in transition. AAC, 4, 60-65.
7. Cohen, C.G. (1986). Total habilitation and life-long management. In S.W. Blackstone (Ed.), Augmentative Communication: An Introduction, (447-469). Rockville, MD: ASHA.
8. Musselwhite, C.R., & St.Louis, K.W. (1988). Communication programming for persons with severe handicaps: Vocal and augmentative strategies, 2nd Ed. Boston, MA: College-Hill Press.
9. Silverman, F. (1989). Communication for the speechless, 2nd Ed. Englewood Cliffs, NJ: Prentice-Hall.

Kathleen A. Kangas, Ph.D.
Speech Pathology & Audiology
Idaho State Univ., Box 8116
Pocatello, ID 83201

USING WORDS STRATEGY™ TO ASSESS GRAMMATICAL CONCEPTS

Kym S. Heine, Prentke Romich Company
Carol A. Trahan, Abilities For Speech and Language
Meher Banajee, Prentke Romich Company
Bruce R. Baker, Semantic Compaction Systems

Abstract

Words Strategy , a Minspeak^{TM} Application Program^{TM} (MAP^{TM}) available for the Touch Talker^{TM} and Light Talker^{TM}, is a word-based vocabulary that is traditionally prescribed for cognitively intact adults. To assist clinicians in determining if such a MAP^{TM} would be appropriate for an individual who is cognitively impaired and/or non-literate, an informal assessment protocol was developed. This protocol systematically assesses an individual's comprehension of the grammatical classes noun, verb, and adjective. The protocol was used to assess 100 non-disabled children ages 6.0 years to 9.11 years. Preliminary normative data and impressions obtained will be discussed.

Background

Technology has made it possible for almost any individual, regardless of the degree of his/her disability, to gain access to a communication device. Once a mode of accessing has been determined, the next hurdle is determining what level of language should be available (i.e. words, phrases, or sentences). Since the majority of one's messages are novel in nature, an augmented speaker should have access to words and phrases or else he/she is required to generate his/her messages at extremely slow rates by spelling.

Proficient use of a word-based system typically assumes that an individual has an understanding of grammatical concepts. If this assumption is valid, then many non-speaking individuals who have poor reading skills and little or no comprehension of English grammar, might not be considered as candidates for the use of Words Strategy^{TM}. This might also dismiss the consideration of those individuals who have not yet received instruction in English Grammar (i.e. children below the third or fourth grade).

Research Question

This paper discusses the use of an informal assessment protocol that will assist the clinician in evaluating a person's comprehension of grammatical concepts. The assessment was designed to answer the question "Can an individual readily learn the concepts of noun, verb, and adjective?"

Method

General Description

The assessment is composed of a Teaching Unit and four Subtests. Eighteen different Words Strategy^{TM} icons were used, each of which produce a noun, verb, and adjective when paired with the appropriate grammar label in a two-symbol sequence as found in Words Strategy^{TM}(1.3). The resulting in 54 vocabulary items were programmed into a Touch Talker^{TM} and the assessment was administered using the device. Only the eighteen Words Strategy^{TM} icons needed for the assessment were placed on the overlay.

The Teaching Unit was designed to provide definitions for the three word classes, as well as practice for obtaining the vocabulary items (i.e. Words Strategy^{TM} icon to grammar icon). Because of the cognitive and language levels of the individuals being tested, the grammar labels noun, verb, and adjective were replaced with "person, place, or thing," "doing words," and "describing words."

The testing portion of the assessment was divided into four Subtests. In Subtests I and II the individual is shown the Words Strategy^{TM} icon and given the target word. The individual is required to select the correct grammar icon to produce the target word. Subtest I provided spoken cues (e.g. "Is ___ a doing word, describing word or a person, place, or thing?") to assist the individual in recalling the word classes.

Subtest II differs from Subtest I in that no spoken cues regarding the three word classes were provided. Subtests III and IV were designed to determine if the individual could sequence four symbols to produce two-word phrases. Cue cards were used in both Subtests as visual aids to eliminate the need to recall the target Words Strategy^{TM} icons for a given word.

Subjects

Although the assessment was designed to assist in determining candidacy for the use of Words Strategy^{TM}, the authors felt it would be helpful to field test the procedures on non-disabled children ages 6.0 through 9.11 years. This age range was chosen because it most closely represented the cognitive and language levels of those individuals who may be questionable candidates for the use of Words Strategy(4). It was anticipated that field testing non-disabled children would assist in establishing a baseline with respect to the cognitive skills required to categorize words into word classes.

Results

Test results were analyzed for each age group according to the mean percent correct for each subtest, accuracy of self-corrections, and consistency of responses across subtests. As predicted by the authors, the mean percent correct increased with chronological age. For example, the mean percentage correct for 6 year olds on Subtest I was 43%, while the mean for 9 year olds was 68%. The mean percentage correct also increased across the first three Subtests for all age groups except the 6 year olds. For example, the mean percentage correct for 7 year olds on Subtests I, II, and III was 51%, 54%, and 67% respectively, while the mean percentage correct for 9 year olds was 68%, 84%, and 86%. The decrease in the mean percent correct from Subtest I to II for the 6 year olds (i.e. from 43% to 35%) was judged to be correlated to the elimination of the spoken cues in Subtest II (e.g. "Is 'win' a describing word, a doing word or a person, place or thing?"), as well as the fact that these children have had little or no exposure to word classes. It should also be noted that the mean percentage correct decreased slightly from Subtest III to Subtest IV across all ages. Several factors could have contributed to this decrease and these will be discussed at the time of the presentation.

The children's ability to self-correct accurately (i.e. individual attempts to self-correct when no spoken cues are provided (e.g. "try again") their errors on Subtests I and II were compared across the age groups. The data obtained indicated that the accuracy of self-corrections increased with age and also increased within each age group from Subtest I to Subtest II. For example, the 6 year olds accurately self-corrected their errors with a mean percent of 47% and 49% of the time, on Subtests I and II respectively, while 9 year olds did so 67% and 77% of the time.

The consistency of responses across Subtests was analyzed for each age group. For example, when an item appeared in Subtest I or II and then again in Subtest III or IV, four possible response patterns could occur. These include:

1. missing an item on Subtest I or II and then again on Subtest III or IV (- -),
2. missing an item on Subtest I or II and then responding correctly on Subtest III or IV (- +),
3. responding correctly on Subtest I or II and then missing the item on Subtest III or IV (+ -),
4. responding correctly on Subtest I or II, as well as on Subtest III or IV (+ +).

When comparing these patterns across the age groups the following was noted. First, the "- - " and the "- +" patterns occurred most frequently in the 6 year olds, with a significant decrease in the frequency for these patterns for the 7, 8, and 9 year olds. Secondly, the mean percentages for the "+ -" response pattern did not vary significantly across age groups (e.g. 19%, 12%, 10% and 9% for the 6, 7, 8, and 9 year olds respectively). It is hypothesized that this response pattern was atypical in the younger children because they "correctly guessed" the items in Subtest I and II, but "incorrectly guessed" the same item in Subtest III or IV. Conversely, the older children who accurately categorized the items in Subtests I or II may miss the items on Subtest III or IV due to a "false negative response." Of particular importance was the mean percentages achieved for the "+ +" response pattern. As expected, the older children achieved a higher mean percentage than the younger children (e.g. a mean of 71%, 54%, 38%, and 19% for the 9, 8, 7, and 6 year olds respectively). This seemed to indicate that the older children readily learned to classify words according to nouns, verbs, or adjectives.

The test results were also analyzed according to the mean percentage correct for the three word classes (i.e., noun, verb, and adjective) for each age group. As expected, the mean percent correct for each word class increased with age. For example, the 6 year olds achieved mean percentages of 48, 36, and 33 for noun, verb, and adjective respectively, while the 9 year olds achieved 79, 76 and 78% respectively. All four age groups achieved the highest percentage correct for the nouns.

With respect to the 9 year olds performance, it is interesting to note that the mean percent correct did not vary significantly across the three word classes. This may have been due to the fact that their linguistic skills have developed to a level of understanding that a word can belong to several word classes. This hypothesis was confirmed when the mean percentage correct for specific words was compared across age groups when presented with and without context. When comparing mean percentages correct for the word "service" across age groups, it was noted that context significantly reduced the performance levels of the younger children but increased the levels for the older children. It appeared that the context defined the word class for the older child but confused the younger child (e.g.

"service" given in isolation could be a noun or an adjective, but "service" presented in the phrase "want service" identifies it as an adjective).

Discussion

Based upon results obtained, it was determined that within the 30-45 minute testing period, that children age 6 years and older learned to correctly categorize words according to nouns, verbs, and adjectives. Performance on the assessment also appeared to reveal information pertaining to an individual's learning styles and response patterns. Additionally, based on the test results obtained, the assumption that an understanding of grammatical concepts is not considered to be a prerequisite to the use of Words Strategy^{TM} was confirmed (i.e. if this knowledge was a prerequisite, then one would assume that the children would have scored significantly lower on this assessment).

Clinical Implications

In addition to obtaining the above-mentioned results, performance on this assessment appears to reveal information pertaining to an individual's learning styles and response patterns. For example, with respect to the use of the spoken cues provided in Subtest I, some of the children seemed to ignore the cues and responded impulsively. Some of these children exhibited a definite trial and error method for selecting their initial responses, as well as their attempts to self-correct (e.g. they always went to noun for their first selection, then to adjective to self-correct). In addition, many of these children were not able to expressively recall all three of the word classes upon completion of the test. Conversely, the children who appeared to listen to the spoken cues (as evidenced by silently repeating them and/or following the clinician as she pointed to each grammar icon) demonstrated an ability to recall the word classes throughout the assessment. These children were observed to silently rehearse the categories before making a selection, and typically took longer to respond. In addition, some of the older children used additional spoken cues such as "to ___ is a verb" to assist them in classifying the target word.

Another type of response pattern that was evident particularly among the younger children included selecting the grammar icon that corresponded with the preceding correct response (e.g. "win" is a verb, so verb was the grammar icon selected for the following vocabulary item). This pattern was typically evident in Subtest II, when the spoken cues are omitted, indicating that the individual could not recall/had not learned the word classes.

Changes in a child's method of selecting his or her responses sometimes became apparent throughout the administration of this assessment. For example, a child may have initially used a trial and error method of categorizing the vocabulary items, but at some point throughout the assessment began to exhibit an actual deduction process, as evidenced by a dramatic increase in the number of correct responses.

Acknowledgement

This research has been graciously supported by Semantic Compaction Systems, 801 McNeilly Road, Pittsburgh, PA 15526.

Kym Smith Heine
300 Sonoma Cove
Madison, MS 39110

17.5

Development of Motor Skills for Communication: A Case Study

Albert M. Cook
Susan M. Hussey
John J. Coltellaro*
Assistive Device Center, CSUS

Abstract

The absence of motor skills in severely disabled clients is a major challenge in developing effective interaction. An approach in which motor behaviors are developed and utilized for environmental and communicative interaction is presented.

Background

One of the most difficult challenges in developing augmentative communication skills in severely disabled clients is the absence of reliable and repeatable motor behaviors which are often characteristic of this population. The apparent absence of controllable motor responses often leads to a generally passive nature on the part of the client, and it can lead to an absence of communicative interaction. This paper describes a case study of a systematic approach to develop motor skills and increase communicative competence in a severely disabled young girl.

Sarah is a nine year old girl with cerebral palsy. She is non-verbal, and she uses her left hand for exploring objects on her lap tray. Sarah is described as very passive and unresponsive, and she often cries in new situations. She does not appear to have any functional vision.

Objective

Sarah was referred for assistance in developing a means of interacting with her environment to initiate choice making and requesting.

Method/Approach

Our interaction with Sarah had four major phases: (1) an initial assessment, (2) a training program of seven months based on the assessment results, (3) a re-evaluation based on this training, and (4) a second phase of training (18 months).

Assessment. The assessment was designed to establish the degree to which Sarah associated switch activation with two contingent results (tape recorder and fan). Two switches with different textures were used for the two objects.

Initial Training. To determine if Sarah would relate the spatial location of a switch to its effect, one switch was connected to music and the other to a fan. Following this, one switch was connected to the home stereo and the other was not connected to any result. The active switch was located near midline. This forced Sarah to move laterally, since the easiest position was near her left side. The inactive switch was placed to the left. To develop her waiting behavior, we used several two-player games from the Interaction Games diskette. Several of these games involve turn taking, and Sarah was encouraged to wait when it was not her turn and to respond on her turn. This training was implemented via sessions at our center and at home with a tutor.

Re-evaluation. In order to re-establish communication goals and choice making, we built on Sarah's ability to use two switch locations using a modified prompt free approach to communication skill development (Mirenda and Santogrossi, 1985). We used the Parrot JK communicator (Zygo Industries) with two phrases: "give me the cup" and "give me the ball". If Sarah chose either item she was given it to play with. This task was chosen because it was repeatable and because she enjoyed playing with these two objects. She was not prompted for any choice, but rather, we played with her and the object requested during the session. We kept track of the number of times that she requested an object when she did not have it in her reach and the number of times she requested it when it was within her reach.

Second Training Phase. Based on the progress which Sarah had made, we decided to increase options for choice making by using the Unicorn keyboard. We were encouraged in this direction by a report (Locke and Mirenda, 1988) in which intervention with a visually impaired child had been based on the use of the Unicorn keyboard with tactile labels and the Talking Word Board Program. We reduced the number of new features in our training task by initially using the Unicorn as a single switch to turn on music. This was done using the Adaptive Firmware Card, the Toy Interface (both Don Johnston Developmental Systems) and a software program which provided an output from the Toy Interface each time the Unicorn key was pressed. This output, equivalent to pressing a switch, was connected to the Ablenet Control Unit and the home stereo. An overlay similar to that described by Locke and Mirenda was built with one 2" square cutout and covered with a textured fabric for tactile feedback. Velcro was used to attach the overlay to the keyboard and the keyboard to Sarah's lap tray. This construction allowed us to position the one available key in several locations on the lap tray. As Sarah skills improved, we added a second switch location with a different texture (see Results).

Results

Assessment. Sarah quickly and easily activated both switches., and she explored the texture of each switch. Sarah correctly hit the switch for the appliance requested (fan or music) 11 times out of 16 trials, and she carefully explored the location and effect of each switch rather than impulsively hitting the first one that she "found".

Initial Training Program. In the task with both switches active, Sarah would choose the requested item about 50-60% of the time, and she would often hit her switch when no request had been made. When only one active switch was used, Sarah hit the music switch between 66 and 75% of the time. We used this task to determine her functional work space by gradually moving the active switch and thereby increasing the distance required for her to reach. Over several sessions, using the Interaction Games Sarah began to wait between her turns with fewer prompts, and the use of the games increased her interaction with her siblings. By this phase of the training Sarah had developed more switch use with her right hand and had demonstrated a wide lateral range with her left hand.

Re-evaluation. Using the Parrot, 66% of Sarah's switch hits were when she did not have the object being requested. The use of two tread switches was difficult because Sarah often appeared to accidentally hit one switch while reaching for the other or by bumping it with a toy. We had also observed that Sarah enjoyed the feel and click of the tread switches.

Second Training Phase. In the initial session using the Unicorn keyboard, Sarah touched the switch location 41 times, but was only able to activate it 14 times. Sarah's performance improved gradually over the next 9 sessions, and by the tenth session she was using the Unicorn as well as she had previously used the tread switch. All of these sessions had used the same location on Sarah's lap tray for the active Unicorn key. We made a major error in our first attempt at finding other key locations. We moved the active location 7 1/2" to the right in one step, since we felt that this wide separation would help her to distinguish the keys. However, she spent most of the time searching for the original key with her left hand, and she quickly became frustrated with the task. We altered our approach to emphasize small changes in location and the use of a shaping paradigm. The active Unicorn key location was moved to the right in 1/2" steps, with control of the stereo and computer games as outcomes. With two sessions per week, Sarah averaged about 4 sessions at each new location before her performance was the same as for the initial location (activation on 80-95% of the trials). Eventually, the total lateral range extended from her left side to her midline position.

Having obtained several locations for active keys, we made a two position overlay using new textures and programmed the Talking Word

Board for requests for cracker and juice. This overlay was used during Sarah's snack time. During each session, we began with the shaping paradigm with music or computer games. Following this the snack time activity was carried out.

An interesting result was that Sarah tended to preferentially use the key location that had been used in the shaping phase during the communication activity, even though it was in a more difficult position. For example, if the shaping paradigm called for a switch location at 3 1/2" and Sarah practiced at that location, she would select this same position in the two choice task. We overcame this limitation by using both locations during the initial portion of the session.

Discussion

The intervention which we have described took place over a period of two years. As Sarah slowly developed new skills, more options became available to her. This included both more choices and a higher degree of motor control. With these increases in skill, her aberrant behaviors (particularly crying) have been reduced, and she is generally happier and more interactive with her family and teachers. Those working with Sarah report that she now appears to have more skills than originally thought. Thus, the development over time of her physical skills has provided gains in her socialization and communication as well.

References

Locke, P. A. and Mirenda, P. (1988) A computer-supported communication approach for a child with severe communication, visual and cognitive impairments: A case study, Augmentative and Alternative Communication, 4: 15-22.

Mirenda, P., and Santogrossi, J. (1985). A prompt-free strategy to teach pictorial communication system use. Augmentative and Alternative Communication, 1(1): 143-150.

Acknowledgment

We are indebted to Dr. Miriam LeGare for providing valuable insight into the development of motor behaviors in clients with severe disabilities.

Albert M. Cook, Ph.D.
Assistive Device Center
California State University
6000 Jay Street
Sacramento, CA 95819

*John Coltellaro
Current affiliation:
Rehabilitation Institute of
Pittsburgh

ALTERNATIVE COMMUNICATION FOR A SEVERELY DISABLED NON-SPEAKING GUILLAIN BARRÉ SYNDROME PATIENT - A CASE STUDY

Trevor J Jones, Edward R Scull, Bioengineering Division, Dept. Medical Physics
Royal Perth Hospital Perth, Western Australia, Australia
John E Wynne, Ward 11, Royal Perth Rehabilitation Hospital
Shenton Park, Western Australia, Australia

ABSTRACT

A 33 year old male victim of Guillain Barré Syndrome who is non-speaking and has severe residual paralysis, is the subject of this case study. The patient survives on a life support system and requires continuous nursing.

Some small movements have returned to his pectoral and triceps muscles, enabling single switch operation.

A combination of a non-technological alternative method of communication together with the Prentke Romich "Light Talker" and DADA's "PC AID" used with an IBM PC-XT computer is described. A gradual consultative approach to developing a comprehensive system is illustrated and the far reaching rehabilitative benefits of the strategy are discussed.

BACKGROUND

It was 2.00am on Thursday morning 4th of April 1985 that John, the subject of this case study, drove alone, along outback roads to Port Hedland. He had a terrible feeling of deja vu. John was in a state of rapid demise of his complete motor system. As a childhood victim of poliomyelitis he knew the symptoms. He used the weight of his body to steer the vehicle and fought to hold his eyelids open. Against enormous odds he arrived at Port Hedland and struggled from the car into the Hospital. Aided by a nurse John managed to walk to casualty - this was to be the last time he walked. A neurological assessment was performed by the registrar but a diagnosis was not forthcoming. A more senior doctor was called in; there was some flipping through books and then eventually the inevitable question of this day and age: "have you taken any drugs?" The answer was an emphatic no, but this reply was not taken on face value. John was given an injection aimed at reversing the effects of drugs and when there was no response to this substance the diagnosis of Guillain Barré Syndrome was made. Four hours later John was totally paralysed, respirator dependent, intravenously fed, had no swallow reflex and therefore required suction clearance of saliva, was blind and unable to speak or communicate.

John was flown some 1800 kilometres by Royal Flying Doctor Service, to Perth. He received treatment consistent with the very high standard of Australia's health care system. In 1985, however, local experience with augmentative communications was limited.

At the very depths of his paralysis John appeared as a "living mass" in which a heart was beating and into which a machine pushed air. He was drifting in and out of consciousness. While conscious his brain was functioning normally and receiving audible input and sensation from pain receptors. From his pain receptors the signals were at times agonising. Likewise the conversations that he heard were sometimes very disturbing. Our first lesson in communication with the very severely paralysed stems from the hindsight of this situation. Never assume that the patient is not receiving. Talk to the patient and inform them as to what is taking place. Don't discuss negative aspects of the patient's prognosis at close range.

Two months after the onset of Guillain Barré Syndrome John regained a small quivering movement in his bottom lip. The doctor who first noticed this movement immediately established a yes/no level of communication. This was enormously significant as it clearly indicated that John's mind was functioning. The same day John's girlfriend devised a way of communicating by vocalising the alphabet in two parts, using the lip movement to signal first half and to make a letter selection. Absence of lip movement signalled second half and again lip movement selected the required letter. This was the first step towards the unlocking of John's mind. This method is still used today and it is referred to as "Spelling".

John was 33 years old when he contracted Guillain Barré Syndrome. At age 6 years he had had a similar although less severe illness from which he fully recovered. John was an automotive electrician and ran his own business in the North West of Western Australia.

His degree of recovery has been only slight and he remains on a life support system. A nurse is in attendance 24 hours per day. Some movement has returned to the left and right pectoral and triceps muscles enabling switch operation with both arms. Sufficient head control has returned to enable a nod for "yes" and a shake for "no". John can also shrug his shoulders for "I don't know". Facial expression is limited but small movements can convey a lot, especially to those who know him. A functional degree of eyesight and thus the important communication adjunct of eye-contact has returned. John has an indomitable spirit and a very strong determination to make the most of his life. His strong will is supported by a keen intellect and excellent memory. John had no prior knowledge of computing.

OBJECTIVE

The hardware and software base to assist people with disability is now available and with careful application can play a highly significant role in the habilitation and rehabilitation of the severely disabled. This case study describes one such application and discusses the extensive ramifications of the technology. A non-technological alternative method of communication known locally as "Spelling" is also discussed.

METHOD: SPELLING

For the first 18 months of John's illness Spelling was the only means of communication available. Whilst it was quite acceptable to John's close relatives (his father and girlfriend) and one or two others, the method did not gain general acceptance until much later. In the face of clearly demonstrated intelligence and a very urgent need to communicate, why was this so? The following are perceived as the reasons:

- John was still a Hospital Unit No. with an interesting diagnosis to most people. There was no pre-existing relationship with the people who attended him to establish his intellectual credibility.

- One small perfectly timed lip movement, without the support of facial expression, eye contact or sound, was not sufficient evidence to a caregiver of a functioning mind with the intent to communicate. Some reflection on the mental processes required of the disabled person in using the Spelling method should have provided the necessary evidence of intact intelligence but this was not so in practice.

- There was most definitely a factor of self-consciousness and, in some cases, lack of self-confidence on the part of the caregiver to stand at the bedside reciting the alphabet whilst watching intently for a very small signal.

- Spelling is a time consuming process (at best twenty characters per minute) and in the ward situation not everybody has the time.

Six years hence, Spelling is accepted and acts as a back stop to the technological methods that are now available.

The reasons for its acceptance are:

- In John's words "At about 20 months a tunnel opened up and I was able to see again". Eye contact was then an available communication accessory and the ability to engage and hold a person's attention improved the efficacy of the Spelling method.

- The technological methods in use today have well and truly established an intellect and personality that is John. John can write freely about himself, the care that he needs and how he communicates. This enables new staff to immediately get to know him and when it is necessary to communicate by Spelling, the barriers are rapidly crossed. The technological method bootstraps the non-technological.

- The embarrassment to the speller of continually reciting the ABC has faded into the background, in much the same way that a person's physical disability fades from centre stage as their personality becomes the dominant part of their identity.

METHOD: LIGHT TALKER

The technology was available to help John communicate more effectively and a Prentke Romich "Light Talker" was chosen. In September of 1986, eighteen months from the onset of Guillain Barré, John was introduced to this device.

A single switch scanning method using a 32 position overlay on the Light Talker (Mode 9) was trialled. John made selections via a rocking lever switch. At this early stage he could see the large print on the overlay as a blur. The very clear flashing L.E.D.'s and audible bleep were essential to the selection process. John could not see the liquid crystal display, but he could retain his progress through a message without visual feedback, and found the audible feedback irritating. John also preferred to convey his message via the display rather than using the speech synthesizer.

There are a set of routine commands that John uses all day and every day to manage his life. Intuitively the expectation would be that routine requests reside in the communication mode of the Light Talker to save having to repeat the same things over and over. In fact these are the least of John's communication problems. There is always a nurse present and in the main they know him well. It takes only two or three letters from one or two word commands, via the Spelling method, to request these vital services.

Commenting, retrospectively, John made the following observations about this phase of the Light Talker's introduction: "The Bioengineering Division introduced me to the Light Talker. At first it was set up with pre-programmed messages such as 'Please move my arm' and the 'Tube is pulling'. This proved to be pretty useless. It had now been 18 months since the beginning of my illness. Feeling a desperate need to express myself I had an ad placed in the local paper for someone to come and spell and write for me. The very same week that a volunteer arrived, Bioengineering reprogrammed the Light Talker with the alphabet and connected it to a printer. This was my first voluntary outlet in twenty months. I set about writing letters, explaining my position and how I felt about my surroundings. It was extremely tedious work. Operating the Light Talker was slow going but my main obstacle was my surroundings" (the hospital routines). "The regular staff read some of the things I wrote and realised that I had something up top. This was a huge step in my attempt to tell everybody that I was still here."

Most of the alphabet and punctuation was transferred to the spell mode and the remaining letters, numbers, editing keys and some addresses etc., were assigned to the communication mode. The spell and communications mode selection keys were included to, in effect, operate like the shift key of a typewriter. At this stage the letters were in alphabetical order as John's vision was still impaired and this familiar layout assisted in the selection process.

John did not use the Light Talker for conversation at this stage. To him it was a writing facilitator and it was well and truly used as such. Another eleven months elapsed before the device was used routinely for talking. To quote, John writes "It was almost a year later that I realised I could use the crystal display on the Light Talker to talk to people, (slow learner), but it wasn't as simple as I thought it would be. Spelling is personal - one to one. It was extremely difficult to get used to communicating through a third medium. The other problem was my slow operation of the Light Talker so I was only able to use this method with a handful of people. The rest would guess too much making the exercise ridiculous. But I was pleased. For the first time in two and a half years, I had had an interactive conversation and this was a breakthrough.

Over the next few months I wrote a file for the staff explaining the best way to do things for me, and the reasons why. This also served as an introduction to me for new staff and agency staff that were only with me for one shift. **This file changed my life.** This was the first time I could go to sleep with the knowledge I had a good chance of seeing tomorrow."

The Light Talker was used with this simple layout for approximately sixteen months over which time John became quite expert in its use and his eyesight improved. The layout was then modified to frequency of occurrence order of the alphabet and after a week's trial it was modified again, at John's request, to place the letters in alphabetical order down the columns. This slightly modified layout did not affect the speed of the selection significantly but helped in the process of memorising the letter locations. The Light Talker is still programmed with this arrangement of letters. John comments on the rearrangement of the scan array: "The next step was to rearrange the alphabet on the Light Talker in frequency of occurrence order. The reason for this change was to allow me to write faster, but the offshoot had a far greater impact. Being able to put the letters up faster meant that I could now talk to anybody, using my own colour of speech. For the first time in three years people began to see me as I really am."

The scanning rate achieved by John results in a production rate of about 60 characters per minute.

METHOD: IBM PC-XT AND PC AID

Via the Light Talker John's ability to think and write was becoming more and more evident. His letters to the Bioengineering Division relating his situation were clear, expressive and wise. It was also known that John had begun to write a book about his life. It was obvious that a better writing tool was needed. Thanks to the generosity of IBM (AUST) a PC-XT computer was donated. PC AID was purchased and in October of 1988 John was introduced to the IBM-DOS environment. In spite of previous computer illiteracy John has thrived on every aspect of computing. The idiosyncrasies of computing have provided a welcome challenge to John and certainly have not been a barrier to its application. In John's own words, "Later that year, Bioengineering introduced me to a computer. It took me a few months to work it out and when the printer arrived the staff could see I was capable of using this equipment.

Thanks to the staff and the people behind the supply of this equipment, for the first time in four years I was seen as an intellectual equal, and treated as one.

I am now using Pc-Write for all my writing, and Pc-Keydraw for graphics. Recently, a rabbit was pulled from the hat. My computer was connected to the telephone network by the fitting of a modem allowing me to use Viatel" (an Australian information service) "and any number of bulletin boards. I have since joined Confer to keep me in touch with the A.A.C. world. This computer is letting me out there in mind, if not in body.

This is just the beginning ....".

METHOD: A COMPLEMENTARY STRATEGY FOR COMMUNICATION

John's system has evolved over a period of six years. Each of the components have specific roles. Spelling is used whenever the Light Talker and/or computer are not available. There are periods during the day when it is not practical or desirable to have the communications equipment in use, e.g., during physiotherapy, when John wants to read or watch television. Spelling provides an adequate means of communication in these situations.

The Light Talker is mounted on John's wheelchair. This provides him with a communication tool on the rare but important visits that he makes outside his room. John also prefers to be in his wheelchair when people visit. The Light Talker is his fastest means of communication and is therefore the most suitable device for conversation.

The Light Talker is also used in combination with the computer. Having both devices available side by side, left arm movement operating the Light Talker and the right arm closing PC AIDS switch, was seen as a milestone in the development of the total system. With both devices in position John could work on his computer without the interruption of routine conversation, the Light Talker filling the latter role. Initially it was either a one or the other situation. With the Light Talker in position John conversed well but could not write. With the computer in position he could write and talk using the command line, but each time he talked it created an interruption to the text or whatever task was in hand.

When John is in bed, and this can often be all day, the computer is available. He has a switch orthosis for use in bed and the monitor is on a sliding and tilting base that enables it to be quickly moved into view over the bed.

This flexibility is crucial to the overall success of the system.

RESULTS

The social implications of this application of the Light Talker, the IBM PC-XT/PC AID/MODEM combination and the careful implementation of this technology have been far reaching for John and the people around him. More than just simple communication has evolved. The benefits of the technology are listed below:

- Mental liberation including the ability to establish an intellectual standing and identity amongst new friends and acquaintances and to reassure old friends that the disability is wholly physical. Further, the technology has enabled John to gain a form of independence and control over his life.

- John's girlfriend was his constant spokesperson and protector for three long and frustrating years. She was constantly by his side and devoted to his wellbeing. Three years ago she sought and was able to adopt a less intense role and began to make a new life for herself. The reasons are socially complex but there is little doubt that the independence gained through technology has had a strong influence in this change.

- John has established a new set of friends. They are from all walks of life but tend to have one thing in common and that is, of course, an intense interest in computers. These people are important. They enrich John's life in many ways. Some are known to him in person, some are on the other end of a telephone line and would not have the remotest idea that, for example their chess opponent has been on a life support system and has not spoken a word for six years. The barrier is down.

John's daughter has a computer and modem available at her foster parents' home. They often chat real time via a bulletin board. When asked the question: Would you like the communication link to be by voice from your daughter and print from yourself? - the answer was very positively 'No'. With both parties using the printed word there is a far greater degree of equalisation, a subtle but very important point.

- Through letters that he writes to his daughter he plays an important role in her upbringing.

- Technology has provided the vehicle for a real purpose in life for John. He is writing an autobiography that to date numbers approximately 120,000 words (approximately 200 pages). This record will provide an invaluable insight into disability and through the force and honesty that is characteristic of John's style, will capture the minds and hearts of all who read it. A clear endorsement of the value of this work was received in October 1990 when John was awarded a writer's grant from the Literature Board - Australia Council, one of five granted to Western Australian writers. John submitted excerpts from the first one hundred pages of his manuscript as the main thrust of his application. John operates PC AID at its maximum scanning speed and seldom misses a selection. He can generate characters at a rate of 40 per minute. In a good week he can add three pages, or approximately 1800 words, to the biography.

- John contributes to the care of other patients in similar circumstances via the written word. He wrote the script and played the leading role in a video presentation that Royal Perth Hospital produced as a teaching aid for the Speech Pathology students of Western Australia.

- The release of unrealistic goals has been a byproduct of the technology. For some time the Rehabilitation Engineering Clinic worked towards independent mobility for John. With the very limited limb and head movements available, wheelchair motor control presented a difficult problem. A wheelchair was purchased and some progress towards head operated controls was made. But there were problems and John wrote a letter on the Light Talker to Rehabilitation Engineering saying that he more than appreciated all that was being done regarding independent mobility, but were we trying to persevere with something that would never work. A few months later, the computer, PC AID and the modem were up and running and he wrote what is surely a very quotable line "I am out there in mind if not in body". The electric wheel chair was passed on to another patient and many hours of what could have been fairly ineffective development time were saved.

DISCUSSION

This case study describes a unique integration of a disabled person with an alternative communication strategy. The system described works for John at this point in time. It grew along with John's understanding and acceptance of the equipment. In this case the support team was also learning, but it is clear in retrospect that the provision of communication aids in general must be backed with resources that can assess, commission, educate, upgrade and service the equipment.

Both the non-technological and technological approaches have important roles in the overall communication system used by John. However, the independence, freedom of expression, privacy and of course the improvement in speed via the technological solutions is very clearly demonstrated.

Further, the application, scope and communications range of John's computer clearly illustrates its power as a vocational rehabilitative tool.

Trevor Jones
Department of Medical Physics-Bioengineering Division
Royal Perth Hospital
Box X2213 GPO PERTH Western Australia 6001
Telephone: (09) 224 2500   Fax: (09) 224 3511

18.1

ENHANCED NEOVASCULARIZATION OF HEALING PRESSURE SORES WITH ELECTRICAL STIMULATION

Steven I. Reger, Shigeharu Negami, Edwin T. Reyes, Akira Hyodo
Department of Musculoskeletal Research
The Cleveland Clinic Foundation

INTRODUCTION

Although it has been previously determined that the electrical stimulation of pressure sores in denervated tissues promotes healing[1], the biological effects of the applied current have yet to be defined[2]. The purpose of this study was to document histomorphometrically the angiogenesis near the end of the healing process and quantitate revascularization in the granulation tissue with and without electrical stimulation.

METHODS

A recently developed animal model for stage 3 pressure ulcers[3] was used to study the angiogenic effect of electrical stimulation. This technique allowed the development of deep, grade 3 or 4 tissue ulcer in the flaccid monoplegic hind limb of the mini-pig using a 3 cm diameter indentor disk anchored by a percutaneous bone screw to the greater trochanter. Ten pigs were used in this study. Five of them were for the direct current group and five were for unstimulated control. The direct current (DC) stimulation of the wound on each pig began the day after wound debridement and continued for three to four weeks, with the wound stimulated for two hours each day for five days each week. The applied DC amplitude was less than 1 mA with a current density between surface electrodes variable from 30 to 80 1A/cm^2. Biopsy specimens were obtained at 3 to 4 weeks after the creation of the wound from the perimeter of the healing pressure sore wounds. Cylindrical 4 mm diameter tissue specimens were removed with a surgical punch from three locations. One specimen was also taken from the innervated opposite limb in each animal. The punch biopsy specimens were then longitudinally bisected and one-half of each was fixed in formaldehyde. Three visual fields at 100 times magnification were observed under the microscope. Each field of 1 mm^2 was selected to be 2 mm below the epidermal surface in the newly formed granulation tissue. Using the Bioquant histomorphometric system, the vessels were counted in each field and their outside perimeter was circumscribed with the laser image projected on the microscope slide. The digitizing tablet and the system software were then used to measure and calculate the enclosed area. All the measurements were summed from the three fields and averaged to express the number of blood vessels per mm^2 or the vascular area per mm^2 of granulation tissue.

RESULTS

At the time of sacrifice, the blood vessel count and the total vascular area was measured from the specimens and the results shown in Table 1. In the DC stimulated wounds, the mean blood vessel count was 19.2 ± 8.2 while the count in the unstimulated control wounds as 9.4 ± 3.1. The combined normal innervated vessel count from the opposite limbs was 9.8 ± 3.7. In the table these values are shown separately for the unstimulated and DC stimulated animals. The DC stimulated granulation tissue contained significantly ($p < 0.05$) more blood vessels than the unstimulated granulation tissue or the normal skin. Histomorphometry showed that the newly formed granulation tissue of the unstimulated wounds contained nearly the same number of blood vessels as the normal hypodermic connective tissue but the vessels in the granulation tissue were mostly enlarged venous arterial and capillary types. The mean value of the total vascular area in the observed fields were $(52.8 \pm 17.2) \times 10^{-3}$ mm^2 in the DC stimulated wounds, $(31.6 \pm 13.9) \times 10^{-3}$ mm^2 in the unstimulated wounds and only $(11.9 \pm 3.81) \times 10^{-3}$ mm^2 in the combined normal innervated skin. (Values are shown again separately for the two sets of animals in Table 1.) The DC stimulated granulation tissue contained significantly ($p < 0.05$) greater total vascular area than the unstimulated and the normal tissue.

DISCUSSION

The vessels in the normal skin were mostly small capillaries while the vessels in the healing granulation tissue were found to be enlarged venous and arterial types. No differentiation of the arterial from the venous vessels was attempted. There were a significantly greater number of vessels with larger total cross-sectional area found in the DC stimulated granulation tissue 2 mm below the epidermal surface than in the nonstimulated granulation tissue at the same depth.

Therefore surface DC stimulation seems to enhance regeneration of blood vessels at least in the upper layers of the granulation tissue. These results demonstrate the angiogenic effect of direct current in the healing granulation tissue by enhancing the number and size of the blood vessels.

REFERENCES

1. Savanu R, Benko M, Stefanovska A, Vodovnik L, Maleric M. Clinical experiences in wound healing by electrical stimulation in SCI patients. RESNA 12th Ann. Conf., New Orleans, LA, 1989, pp. 171-172

2. Reger SI, Negami S, Reyes ET, *et al.* Effect of DC electrical stimulation on pressure sore healing in pigs. RESNA 13th Ann. Conf., Washington, DC, 1990, pp. 379-380

3. Negami S, Reger S, *et al.* An experimental pressure sore model for functional electrical stimulation -- Continuous pressure application on monoplegic pigs. *In:* Advances in External Control of Human Extremities X, Naucna Knjiga, Belgrade, Yugoslavia, 1990

TABLE 1. ANGIOGENESIS AT THE END OF HEALING

Animal Number	Number of Vessels per mm^2		Vascular Area x10^{-3} mm^2/mm^2	
	Denerv. Limb	Innerv. Limb	Denerv. Limb	Innerv. Limb
Unstimulated				
1	8.5±4.0	---	33.4±17.7	---
3	7.6±4.2	12.0	29.5±21.5	16.8
5	8.1±0.7	12.0	39.1± 6.2	18.3
7	10.4±3.8	7.3	23.2±12.3	7.5
9	11.7±1.9	10.0	33.4±15.7	11.0
Mean±S.D.	*9.4±3.1	10.3±2.2	*31.6±13.9	13.4±5.0
DC Stimulated				
2	11.5±5.9	18.7	41.5± 2.0	6.9
4	16.3±4.7	7.0	63.5±20.3	11.1
6	13.4±1.2	6.3	35.4± 7.9	11.6
8	27.4±7.4	7.7	61.6±17.7	13.1
10	27.7±5.2	6.7	61.0± 9.8	11.1
Mean±S.D.	*19.2±8.2	9.3±5.3	*52.8±17.2	10.8±2.3

*$p < 0.05$

ACKNOWLEDGEMENT

This study was supported by a grant from NIDRR #H133A80030-90.

Steven I. Reger, Ph.D.
Department of Musculoskeletal Research
The Cleveland Clinic Foundation
9500 Euclid Avenue
Cleveland, OH 44195-5254, USA

18.2

SPASTICITY IN SCI: DAY-TO-DAY VARIABILITY IN RESPONSE TO JOINT MOVEMENT AND ELECTRICAL STIMULATION

Joyce Campbell, Paul Meadows, Robert Waters, Charles Carter,
Lynn Kashitani, Susan Oda, Leslie Miller
Rancho Rehabilitation Engineering, Downey, CA
California State University, Long Beach, CA

ABSTRACT

Spasticity alters voluntary (VOL) and electrically stimulated (ES) muscle performance and associated function. Research designs to study spasticity or muscle strengthening must consider spasticity as a correlate in measurement. The purpose of this study was to measure resistance to passive joint motion (RPJM) and related intramuscular electromyographic (IM-EMG) responses at 6 velocities before and after ES. PJM was performed in 7 SCI subjects (30,60,90,120,180 and 230 deg/s and the series was repeated twice before and twice after quadriceps ES. PJM was controlled by an isokinetic device. An IBM PC/AT sampled voltages for calibration, gravity compensation (GC) and data acquisition. Fine wire electrodes recorded EMG for integration and transfer to the IBM. Repeated testing was done on 4 subjects. Repeated measures ANOVA revealed an increase in RPJM and EMG across velocities ($p<.001$) and a decrease in both after ES ($p<.001$). SCI subjects differed on retest. RPJM was related to recruitment curve characteristics and ES muscle performance ($p<.001$). These findings have application to goal setting in SCI, to research protocols and to the design of computer-controlled ES systems.

INTRODUCTION

Spasticity, or involuntary contraction of muscle in response to stretch, may augment or interfere with limb movement as its severity fluctuates from time to time. VOL or ES muscle performance and associated functional activity, such as walking, vary in quality along with the variance in spasticity of the muscle under study or of its antagonist (1,2). Determination of the relative merits of therapies designed to reduce spasticity or to strengthen muscle in order to improve function must take this variable into account. The lack of objective characterization of spasticity is not surprising when the difficulties in measurement are considered. An ideal measurement system would simulate the amount and rate of muscle perturbation that occur in patient function. Such a system also would place the individual in the position of function and orientation in space required for daily activity (ie in the standing position with hip, knee and ankle in the critical positions for upright mobility). Unfortunately, there is no ideal system at the present time. PJM has been used to demonstrate a velocity dependent resistance to movement in spastic patients (3-5). RPJM was significantly greater in SCI than in normal (N) individuals (5).

Reports on the effectiveness of ES in the reduction of spasticity have appeared in the literature since the 1800's (6). Electrical stimulation temporarily reduced spasticity in hemiplegic, SCI and cerebral palsied patients, and trends toward a 24-hour per day effect of chronic ES on spasticity have been reported (8-9). Protocols for ES and for evaluation of spasticity have varied as have the extent of motor and sensory deprivation in the subjects. Activation of reciprocal inhibition or spinal inhibitory interneurons (Renshaw cells) in response to ES may differ in patients with complete versus partial paralysis (9-11).

The purpose of this study was to measure RPJM and associated IM-EMG in the quadriceps and hamstrings at six velocities of motion before and after ES.

METHODS

Subjects: Seven healthy SCI patients (3 quadriplegic and 4 paraplegic men) were studied. Time since onset of SCI ranged from 4 months to 17 years. Subjects were unable to contract the quadriceps and sensation was absent or severely impaired. Subjects experienced spasticity in their daily life, but it did not prevent function. Medication regimens were constant during the study period.

Instrumentation: PJM was controlled by an isokinetic system (LidoActive, Loredan Biomedical, Davis, CA). Analog signals were sampled by an IBM PC/AT for angular position, velocity and moment. Prior to data acquisition, calibration and GC (5 deg/sec) were performed. 50u stainless steel wire electrodes, insulated to 1-2 mm from the tip were used to record EMG signals. A 10 Hz filter removed movement artifact and signals were amplified for rectification and integration (time constant: 200 msec) and sampled by a Data Translation DT2821 12 bit analog-to-digital converter at 100 Hz. ES pulses were generated by a circuit board in the IBM PC/AT (asymmetrical biphasic pulses, 300 usec duration and 33 pps). Moment voltages were used as feedback to modulate stimulus intensity.

Procedure: Subjects were asked to refrain from smoking or injesting substances that might alter muscle responses for 24 hours prior to the test. Before PJM, IM-EMG electrodes were placed in the vastus lateralis (VL) and the long head of the biceps femoris (BFLH). Ten cycles of PJM were performed sequentially at each velocity (30,60,90,120,180 and 230 deg/s). Immediately following, the PJM series was repeated. Raw and processed EMG were observed during each joint oscillation to verify the presence or absence of motor unit action potentials.

An ES recruitment curve (60 deg/s) was performed to determine the stimulation intensity required to produce approximately 50% of maximum ES knee extension moment. This value (Nm) was used as a target for the following 40 ES knee extensions (60 deg/s). ES intensity was adjusted to maintain the target moment when a deviation of ± 2 Nm was noted. Peak moment and work were documented for each ES knee extension. The six PJM velocities were repeated within 4 minutes and at 30 minutes after the ES exercise. Four of the subjects returned on a second day.

Moment and EMG were plotted against knee position for visual analysis and EMG (A/D units, ADU), peak moment (Nm) and resistance work (Nm-deg) were calculated for individual or summed PJM cycles. The BMDP statistical package was used for descriptive statistics, correlations, repeated measures ANOVA and t-tests with a Bonferonni adjustment of the alpha level.

RESULTS

SCI subjects varied in RPJM and in the temporal nature of reflexive activity. Spasticity was documented at 30 deg/sec in some subjects while in others the velocity threshold was above 180 deg/sec. EMG was most commonly observed near knee extension (hamstring EMG) or near flexion (quadriceps EMG), but EMG was present throughout the range in some instances (Fig 1). Individual velocity thresholds for the VL and the BFLH were seen. RPJM and EMG were greatest in the first few cycles of knee motion (ie cycles 1-3) in selected subjects, and it persisted throughout the 10 cycles in others (Fig 2).

There was no statistical difference between the first and second series of PJM within a test session. However, in several subjects knee movement in the first series of 6 velocities resulted in lower RPJM as well as reduced EMG in the subsequent measurements (Table 1).

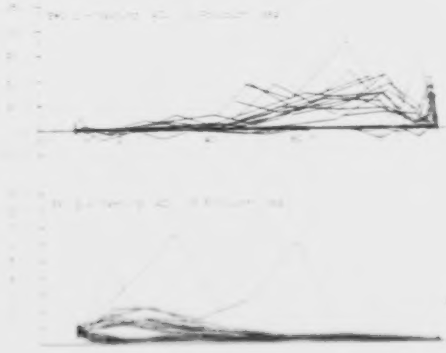


Fig 1. EMG (ADU) from the VL (top) and BFLH (bottom) versus knee position (16 - 87 deg flexion). Reflexive quadriceps activity was greatest in knee flexion and hamstrings were most active near knee extension in this paraplegic subject.

RPJM and EMG of both BFLH and VL increased with velocity of knee motion (p<.001). A reduction in RPJM and EMG was observed in the immediate post-stimulation PJM series (p<.01). Although there was no significant difference between the immediate post-stimulation measurements and those taken 30 minutes later, there was a trend toward a return to pre ES values. Not all subjects improved after ES. Hamstring spasticity increased after stimulation in one subject and limited knee extension after ES (Fig 3).

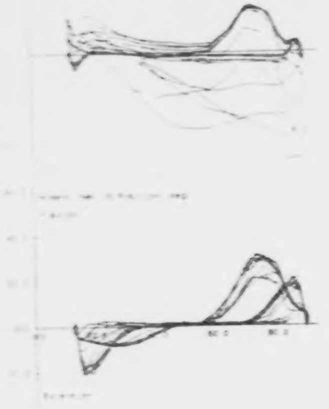


Fig 2. Moment (Nm) versus knee position (deg) for 12 cycles of PJM. The greatest RPJM occurred in the first 4 cycles at 180 deg/sec in the first test (top) while RPJM was consistent across cycles, once the Lido moment arm reached 180 deg/sec.

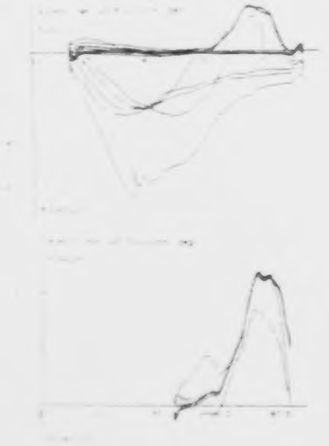


Fig 3. Moment and EMG vs position (30 deg/sec). Pre-ES range=16-87 deg knee flexion (top). Post-ES range=45-83 deg knee flexion (bottom). Hamstring spasticity prevented knee extension and quadriceps RPJM was reduced after ES.

RPJM, peak ES knee moment, ES work during the 40 ES contractions, the rate of fatigue during ES and the change in moment after ES differed from one patient visit to the next (Table 1,). RPJM was related to the responses to ES on any one visit. Recruitment curve characteristics and ES responses were predictive of RPJM when ES peak moment, and the rate of ES fatigue over 40 knee extensions were included in the regression analysis (p<.001, F=9.3).

BEST COPY AVAILABLE

Table 1. RPJM and ES muscle performance on two days in one paraplegic subject. PJM at 6 velocities, Series 1, immediately followed by Series 2.

RPJM	Visit 1		Visit 2	
	Series 1	Series 2	Series 1	Series 2
VEL	RW *	RW	RW	RW
30	98	86	908	729
60	86	110	1086	759
90	178	196	447	805
120	295	310	932	501
180	656	627	876	779
230	721	829	1060	934

	Visit 1	Visit 2
Recruitment Curve		
PM **	36 Nm	19.4 Nm ****
SI ***	110 mA	60 mA
ES Exercise (Target = 12 Nm, 40 repetitions)		
Total Work (Nm)	267	167
Time to 50% ↓ Nm(sec)	120	72
RPJM after ES (Nm)		
30 deg/sec	↑14%	↓55%
230 deg/sec	↑36%	↓47%

* RW = Total resistance work (Nm-deg)
** PM = Peak moment (Nm)
*** SI = Stimulus intensity (ma) associated with PM
**** Hamstring spasticity reduced PM at >60 mA

DISCUSSION

The methodology employed in this study can be used to characterize spastic knee responses in SCI patients during a particular test session. Each patient demonstrates a unique pattern in terms of velocity threshold, location of reflexive response in the range of knee motion and the persistance of the response over repetitive movement of the joint (ie cycles 1, 2 and 3 versus cycles 7 through 10). SCI subjects vary from day to day and resistance work values measured in one visit cannot be used to normalize data gathered at a different time. Spasticity does appear to influence ES recruitment curves and ES muscle performance in a predictable way. It is proposed that a measure of spasticity be used to normalize ES muscle performance to establish baseline data and to detect change as a result of intervention.

Although there was a statistical reduction in RPJM and IM-EMG activity immediately following ES, not all subjects were improved. Additional data are needed to improve the confidence of this conclusion. The laboratory stimulation system employed here did not permit ramping of the stimulus intensity which would reduce the possibility of eliciting hamstring spasticity (Fig 3).

Technical and procedural considerations need to be given to the SCI patient when an isokinetic device is used. First, GC must be done at the slowest possible velocity (ie 5 deg/s) to avoid muscle contraction as the limb is weighed throughout the joint range. Second, the inertial effects observed at the end ranges may be omitted from the analysis of normal joints (1). This omission, however, would eliminate RPJM seen near the extremes of joint motion in the spastic patient. Third, the moment arm acceleration period, that my be ignored in normal individuals, may be the time when the spastic patient is demonstrating both resistance work and EMG activity. All cycles, 1 through 10, must be studied with the understanding that the first few cycles are not at the target velocity.

The information obtained in this preliminary study can improve documentation of the outcome of ES protocols designed to augment muscle performance. It also has application to the design of computer-controlled stimulation systems. Manual adjustments need to be available to modify stimulation parameters, at least in a global fashion, to accommodate for changes in spasticity on a daily basis if ES systems are to be useful in the home, school and workplace.

ACKNOWLEDGEMENTS

Funding for this research has been provided in part by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant No. H133G80142. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of NIDRR.

REFERENCES

1. Waters RL, Campbell JM, Nakai R: Therapeutic Electrical Stimulation of the Lower Limb by Epimysial Electrodes. Clin Orthop 233:44-52, 1988.
2. Vodovnik L, Rebersek S, Stefanovska A, Zidar J, Acimovic R, Gross N: Electrical stimulation for control of paralysis and therapy of abnormal movements. Scand J Rehab Med Suppl 17:91-97, 1988.
3. Knuttson E: Analysis of gait and isokinetic movements for evaluation of antispastic drugs or physical therapies. Adv Neurol 39:1013-1034, 1983.
4. Burke D, Andrews CJ, Gillies JD: The reflex response to sinusoidal stretching in spastic man. Brain 94:455-470, 1971.
5. Campbell J, Waters RL, Meadows PM, Nakai R, Carter CL, Grek AE, Miller L, Gillim RL: Spasticity: Correlate of FES Motor Performance In Spinal Injury. In Popovic D [Ed]: Adv Ext Control Human Extremities X, Belgrade, Yugoslav Committee for Electronics and Automation, pp 601-613, 1990.
6. Levine MG, Knott M, Kabat H: Relaxation of spasticity by electrical stimulation of antagonist muscles. Arch Phys Med Rehabil 33:668-673, 1952.
7. Stefanovska A, Gros N, Vodovnik L, Rebersek S, Acimovic-Janezic R: Chronic electrical stimulation for the modification of spasticity in hemiplegic patients. Scand J Rehab Med Suppl 17:115-121, 1988.
8. Nashold BS, Grimes J, Friedman H, Semans J, Avery R: Electrical stimulation of the conus medullaris in the paraplegic. Appl Neurophysiol 40:192-207, 1977.
9. Dimitrijevic MR: Neurophysiology in spinal cord injury. Paraplegia 25:205-208, 1987.
10. Pierrot-Deseilligny E, Katz R, Hultborn H: Functional organization of recurrent inhibition in man: Changes preceding and accompanying voluntary movements. In Desmedt, JE [Ed]: Motor Control Mechanisms in Health and Disease. New York, Raven Press, pp 443-457, 1983.
11. Tanaka R: Reciprocal Ia inhibitory pathway in normal man and in patients with motor disorders. In Desmedt, JE [Ed]: Motor Control Mechanisms in Health and Disease. New York, Raven Press, pp 433-441, 1983.

Joyce M. Campbell, Ph.D.
Rancho Rehabilitation Engineering
7503 Bonita St, Downey, CA 90242

ENDOGENOUS POTENTIALS OF HUMAN SKIN INJURIES

Aleksandra Jerčinović, Stanislav Reberšek, Lojze Vodovnik, Fedja Bobanović
Faculty of Electrical and Computer Engineering, University of Ljubljana, Ljubljana, Yugoslavia

Abstract

The present study deals with endogenous potentials of skin injuries (abrasions, pressure sores) in humans and their role in the healing process. The preliminary results consistently demonstrate positive and markedly higher potentials at the injury sites (ranging from 22 to 54 mV), compared to the potential of intact skin surface. The effects of electrical stimulation on endogenous potentials of pressure sores were examined as well.

Introduction

The endogenous electrical properties of living systems and the possible employment of externally applied electricity for influencing natural processes appear to be a complementary phenomena which have been motivating researchers through centuries /1/.
Chronic wounds are a troublesome problem with complex and not totally understood etiologies and it concerns a numerous patient population (spinal cord injured (SCI) patients, immobile elder people, diabetic patients etc.). Due to difficulties in preventive treatment, which would remain the best approach to this problem, electrical stimulation modalities seem to be an effective and simple method for treating chronic wounds/2,3/. However, due to the lack of knowledge regarding the mechanisms through which electrotherapy might augment soft-tissue healing, application and confidence in this promising treatment has not increased proportionally to its benefit.
Our search for an explanation of the influence of externally applied electrical current on the healing process led us to the measurement of endogenous electricity /4,5/. Although we are still far from determining the role and significance of bio-electric potentials (endogenous potentials) in the wound healing process, we present the preliminary results of the endogenous potential measurements of injured human skin. Due to ethical and practical reasons, measurements of voltage gradient over experimental wounds in humans by means of the progression of injury into deeper tissue planes are not feasible. Therefore, potential measurements were performed on two types of injuries: skin abrasion in healthy volunteers (affected epidermis) and pressure sores in SCI patients (tissue damage down to subdermal space). The purpose of our study was to identify the endogenous potential of the abrasions/pressure sores and intact surrounding skin and from the obtained values make an assumption regarding the location of possible sources of endogenous potential. Our intention was also to examine the possible effects of electrical stimulation (ES), used to enhance the wound healing, on the endogenous potential of the pressure sores and the surrounding skin.

Method

For the endogenous potential measurement an instrument with a Burr-Brown electrometer amplifier 3431J (differential input impedance of $10^{11}\Omega$) was used. In order to insure low DC resistance of the electrode/electrolyte interface and a stabile half-cell potential, Ag-AgCl electrodes were chosen. Electrical contact between the sterilized electrodes and the tissue was made through physiological solution. The electrodes had an electrode potential of less than 2 mV and a drift of less than 0.5 mV per hour. The electrodes were checked before and after each measurement. Positioning of the electrodes was performed by means of a manipulator. Initial transient phenomena lasted for less than 1 min. The readout was done after a quasi-stationary (up to ±3mV) value was attained for at least 3 min.
The measured voltage (endogenous potential) was the difference between the potentials of the two selected points with the reference electrode always placed distally on intact skin. The measurement setup is shown in figure 1.

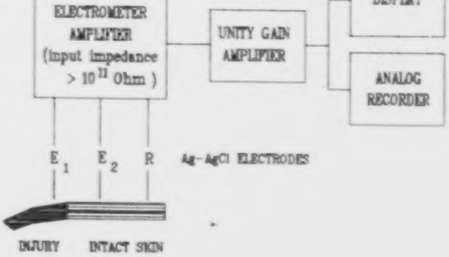


Figure 1. Measurement setup.

Abrasion

In order to identify the endogenous potential of the abrasion, 8 healthy volunteers were involved in the study. Electrical measurements were done on the skin surface of the forearm as follows: on intact skin (during 5 successive days), intact skin just before abrasion, immediately after it and daily during the healing process (up to 9 days). The measured voltage was the difference between the potentials of the two selected points on the skin; first intact - intact, and then (after the abrasion) intact - injured. The abrasion was about 1.5 cm^2 large.

Pressure sore

Endogenous potential measurements were performed on 4 SCI in-patients having sacral pressure sores (tissue damage including subdermal space). The preservation of the measurement protocol used in case of abrasion was impossible. The measurements of the endogenous potentials of the patient's sacral skin area before development of the pressure sore were not feasible. Also due to a long term healing (a few months) required for such sores, it would be hard to follow the endogenous potentials during the healing process. Therefore, the endogenous potentials of the close surrounding of the sores compared to the intact skin were measured, followed by the endogenous potential measurement of the pressure sores compared to the same intact area. Measurements were performed during 5 successive days. In the case of 2 patients treated with ES to enhance the healing process of the pressure sore /3/, the above described measurement procedure was performed before and immediately after 2 hours of ES. Constant direct current of an amplitude of 0.6 mA, with two electrodes placed on the intact skin in the sore surrounding, was used.

Results

Abrasion

The measured potentials of healthy intact skin were within the range of 15 to -10 mV. The endogenous potentials before and immediately after abrasion are shown in figure 2. The endogenous potentials of the abrasions were found to be more positive (ranging 28 - 41 mV) compared to the potential of intact skin. A general tendency of the endogenous potentials during the healing process, reported by Burr et al. /6/, was not observable. After the healing was completed measured potentials on 'scar sites' were within the range of those measured on intact skin.

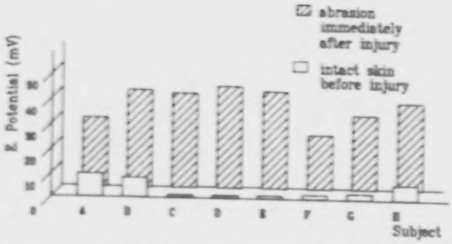


Figure 2. Endogenous potentials before and immediately after the abrasion.

Pressure sore

The endogenous potentials of the pressure sores (22 to 54 mV) were markedly higher than those of the sore surrounding in all measurements, regardless of the sore treatment (conventional or with ES). In the patients receiving ES, less consistent values of the endogenous potentials of the sore surroundings, varying in sign and amplitude, were observed. The results presented in figure 3. suggest the enhancement of the difference between the potential of the sore and the one of its surrounding being influenced by ES.

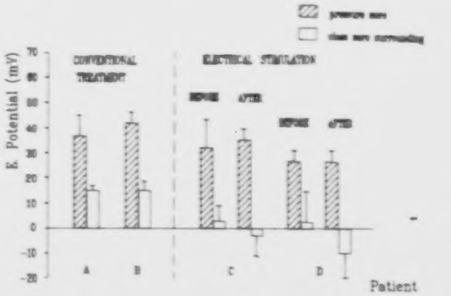


Figure 3. Endogenous potentials of the pressure sores and their surrounding area (mean±S.D.).

Discussion

The endogenous potentials of injured human skin were found to be positive and significantly higher than the variable baseline value obtained on intact skin surface (stratum corneum). The measured voltages of abrasion on forearm are within the range of transepithelial potential measured by Barker et al. /4/. The changes in sign of endogenous potential during the healing, reported by Burr et al. /6/, were not observed.

Even though the comparison of endogenous potentials of an abrasion and a pressure sore is not adequate due to difference in skin, underlying tissue and general state of health, it is interesting that the results suggest the injury with a greater degree of affected tissue not to be associate with significant additional endogenous electrical activity. However, the number of sores included in the measurements is too small to draw a conclusion and an extended study is needed.

References

/1/. Wu, C. H., Electric Fish and the Discovery of Animal Electricity, Am Sci.,72, 598- 607, 1984.

/2/. Dayton, P.D., Palladino, S.J., Electrical Stimulation of Cutaneous Ulceration - A Literature Review, J Am Med Assoc. 79(7), 318-321, 1989.

/3/. Stefanovska, A., Vodovnik, L., Benko, H., Maležič, M., Turk,R., Kolenc, A., Reberšek, S., Enhancement of Ulcerated Tissue Healing by Electrical Stimulation, Proc. RESNA 10 th Ann Conf., San Jose, 585-587, 1987.

/4/. Barker, A. T., Jaffe, L. F., Vanable, J. W., The Glabrous Epidermis of Cavies Contains a Powerful Battery, Am J Phys. 242, R358-366, 1982.

/5/. Borgens, R. B., What is the Role of Naturally Produced Electrical Current in Vertebrate Regeneration and Healing?, Int Rew Cytol. 76, 245-298, 1982.

/6/. Burr, H. S., Taffel, M., Harvey, S.C., An Electrometric Study of the Healing Wound in Man, Yale J Biol Med. 12, 483-485, 1940.

Acknowledgement

The clinical part of the study was performed at Spinal Cord Department of the University Rehabilitation Institute, Ljubljana, Yugoslavia. The study was supported by Ministry of Science, Research and Technology of the Republic of Slovenia, Yugoslavia; NIDRR, Department of Education, Washington, D.C.; and the Commission of the European Communities, Directorate-General for Science, Research and Development, International Scientific Cooperation, Brussels.

Aleksandra Jerčinović
Laboratory of Biocybernetics
Faculty of Electrical and Computer Engineering
Tržaška 25, 61000 Ljubljana
Yugoslavia

DIFFERENT MODES OF ELECTRICAL STIMULATION FOR REDUCTION OF SPASTICITY IN CP CHILDREN

Stanislav Reberšek, Alenka Kolenc-Krajnik, Ana Klemen*& Vesna Zeljič*
Faculty of Electrical and Computer Engineering, University of Ljubljana
*University Rehabilitation Institute, Ljubljana, Yugoslavia

Abstract

The effect of electrical stimulation with direct motor response and without it on spasticity of ankle joint muscles were studied. Resistive torque of ankle joint passive movements on Achille's tendon reflex for observation of spasticity was used. A decrease of tonic stretch reflex was observed with both types of stimulation, while the ratio of Achille's tendon reflexes remained unchanged.

Introduction

In the therapy of children with cerebral palsy (CP) there are generally various therapeutic methods used to facilitate realizable motoric patterns. As a result of secondary consequences of the motoric deficiency, surgical interventions are not rare, such as for instance the lengthening of the Achille's tendon etc. Before and after a surgical intervention; such children are given - at least in advanced centers - a type of therapy which is based on neurophysiological principles. Among these types of therapy the most known is the Bobath method (1). Together with these methods the functional and therapeutic electrical stimulation (2) has been found as an extremely applicable method. Similarly as other therapeutic methods, electrical stimulation is also not universally applicable. On one side this means that it cannot be expected to achieve the same success in all children, and, on the other one, the electrical stimulation can even be contraindicated. Namely, investigations of Gračanin and his co-workers (2) have shown that the functional and therapeutic electrical stimulation is most successful in children with a pure spastic paresis, while in children with atetosis or ataxia the results are considerably less significant or there are none. According to Gračanin, electrical stimulation is even contraindicated in cases in which clinical signs of hypotonia are present, because the inhibitory effect of the electrical stimulation additionally worsens the equilibrium of forces necessary for stabile standing and walking.

The studies made so far have been based on the stimulation of the n. peroneus, while the target of the described study is to find and to compare the effects of additional modes of stimulation on spasticity in CP children. For the time being the study is limited to short term effects of a half an hour lasting stimulation. The principal task is to find out the difference between the passive stimulation while sitting and the active stimulation during walking for two different types of the stimulation. To allow a direct comparison with the results of other studies performed, the already mentioned stimulation of n. peroneus was chosen for the first mode, and the stimulation of dermatomes S_1, S_2 for the second mode. The stimulation of dermatomes was selected as a result of the fact that investigations in paraplegic patients (3) have shown that this type of stimulation can have quite greater impact on the lowering of the abnormal reflex activity than the usual efferent stimulation of the motoric nerve. On the other side such a type of stimulation has practically no effect in hemiplegic patients (4). It was therefore of interest to discover the effects of dermatome stimulation also in CP children.

Measuring method

Among methods for the assessment of the spasticity in children those one that give clinically applicable results and at the same time do not trouble the child by long measurements or do not cause painful intervention should be chosen. The following two methods seem to be suitable for children according to above criteria: measurement of resistivity to the passive motion at various speeds and measurement of the Achille's tendon reflex. Thus we decided to implement them in our study. The measurement of the resistivity to the passive motion is widely used for testing of spasticity and it is described by many authors (5). For the assessment of the resistance the average value obtained from four different frequencies (0.1, 0.5, 1 and 2 Hz) of the motion along the sinusoidal trajectory of the position in the ankle was used in the present study. The mean value of the resistance at each individual frequency was calculated on the basis of ten subsequent motions of the ankle. The overall resistance as a measure of spasticity before or after application of stimulation was then calculated according to the formula:

$$R = \frac{1}{4} \sum_{j=1}^{4} \frac{1}{10} \sum_{i=1}^{10} r_{i\ max}$$

where:

$r_{i\ max}$ - maximal value of resistance to the passive motion within one period and at one frequency (f_j; $j = 1, 2, 3, 4$)

It is important that beside the resistance as one of the parameters which indicates the spasticity status, also a electromyagraphic activity (EMG) of agonistic and antagonistic muscle group is measured. The EMG measurements provide a better insight in changes occured after application of electrical stimulation regarding the tonic and phasic part of stretch reflex activity. To detect the EMG activity of agonistic and antagonistic muscle group, disc electrodes (silver-silver cloride) of 1 cm diameter were used, located in pairs at the distance of 3 cm between each other above the tibialis anterior and soleus muscles. All the four signals (2 EMG channels, position and resistance) were simultaneously registered during the measurement on a paper and magnetic tape recorder.

Apart from the resistivity to the passive motion, the measurement of the Achille's tendon reflex was implemented to provide a rough assessment of excitability in the reflex loop. Since this measurement is known and generally applicable in neurophysiology, it will not be described in detail, nevertheless we consider it necessary to mention which of the reflex parameters were used in the study. At each measurement, the average response pattern was calculated, constituting of 32 subsequent awakenings of the tendon reflex, following each other in the time interval of 2 s. Owing to the fact that in CP children it is the reciprocity function that can be highly effected - so that there may even be incidences of the reciprocic excitation (6) - the ratio between the maximal amplitude of responses in the tibialis anterior and the soleus muscle was taken for the estimation of the excitability state.

The clinical tests over four measurements were made on each child. The time interval between individual measurements was at least 7 days in order to avoid the influence of an eventual delayed effect of the stimulation mode in the forme treatment on the results. The measurements followed each other in the following order: the first measurement was meant to assess the effect of the stimulation of the n. peroneus during walking, the second one the effect of the stimulation of the n. peroneus without walking, the third one the effect of the stimulation of dermatomes without walking, and the last one the effect of the stimulation of dermatomes during walking. Each time the duration of the stimulation was half an hour. Prior to the stimulation the entire measurement had been performed (resistance to passive movement and ATR) to document the present state of the spasticity. Immediatelly upon the stimulation a second measurement was performed under the same conditions as the first one.

Measurement results

Ten children were measured according to the described protocol. In seven of them a measurable decrease of the average resistance to the passive motion was noted in the range between 10 - 25 % of the value measured directly before application of the stimulation; in other three children the changes were nonsignificant. The decrease of the resistance was simultaneously accompanied also by a change of patterns of the EMG activity in both muscles which exhibited itself as a decrease of the tonic component of the stretch reflex, while no important changes of phasic component were noted in any of the casess. Fig. 1 shows the changes of the resistance for one child obtained at all four types of stimulation. In the remaining six children the changes of the resistance were similar although of lower values. In addition to the changes of the resistance, the change of EMG pattern is shown in Fig. 2 for the same child before and after dermatome stimulation without walking and at 2 Hz of passive motion. Regarding different kinds of the stimulation it has to be pointed out that they were approximatelly equally effective in decreasing the resistance in all children, since the small differences were nonsignificant. Similar are also the results of the measurements of the Achille's tendon reflex. The comparison of ratios showed, that in no case there was an evident change in spite of the fact that the absolute values of the response to taps on the tendon after the stimulation were smaller in some children up to 60% and the amplitude increased in none of the cases.

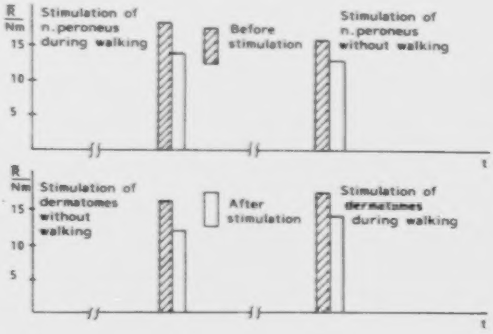


Fig.1. Effects of different stimulation procedures on decrease of resistance in subject K. A.

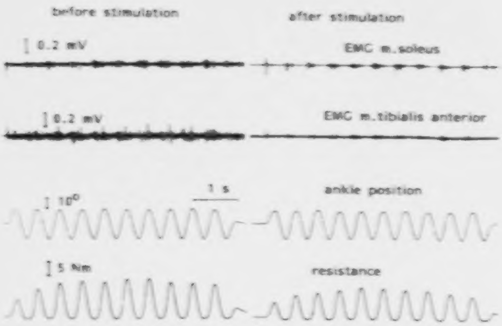


Fig.2. Comparison of resistance to passive motion and EMG activity in tibialis anterior and soleus muscles before and after stimulation of dermatomes during walking for subject K. A.

Conclusions and discussion

The so far obtained results of the study show that the exteroceptive stimulation without a direct motoric response is for CP children equally efficient with regard to the reduction of the resistance as the stimulation by a direct motoric response. This is quite surprising with regard to the hemiplegic or paraplegic patients. Thus at the same time it proves the fact that the pathology of CP children is neither exactly like those in hemiplegic nor in paraplegic patients. Practically any kind of stimulation can produce the reduction of the resistance always accompanied by the reduction of the tonic activity as a response to the induced motion of the ankle. The rate of changes of the tonic response is such that it is not possible to have it attributed only to the known weak repeatability of parameters, that characterize spasticity. It is interesting that in some children none of the stimulation procedures proved to be effective. The results of Achille's tendon reflex are partially consistent with the findings of Gottlieb et al. (6) since the unchanged ratio between agonist and antagonist EMG does not mean that the excitability on the level of the motoric neurons has not changed, i.e. decreased, particularly as we have noticed in most of the children a lower absolute value of this response. Such a decrease is of course additionally proved with the disappearance of the tonic component of the stretch reflex detected through passive motion. It seems therefore that electrical stimulation can decrease the overall excitability of the motoric neurons.

Acknowledgements

The financial funds for the study have been provided by the Ministry of Science, Research and Technology of the Republic of Slovenia, Yugoslavia, and NIDRR, Department of Education, Washington, D.C. Their support is herewith thankfully acknowledged.

References

1. Bobath, K.: Neurophysiological Basis for the Treatment of Cerebral Palsy. Clinics in Developmental Medicine No. 75. Oxford: Blackwell Scientific Publications Ltd. Philadelphia, 1980
2. Gračanin, F.: Functional Electrical Stimulation in Control of Motor Output and Movements. Contemporary Clinical Neurophysiology: EEG Suppl. No. 34: 335-367, 1978
3. Bajd, T., Gregorič, M., Vodovnik, L., Benko, H.: Electrical Stimulation in Treating Spasticity due to Spinal Cord Injury, Arch. Phys. Ther., Rehabil., 66: 515-517, 1985
4. Stefanovska, A., Vodovnik, L., Reberšek, S., Bajd, T.: The Role of Electrical Stimulation in Understanding Spasticity, Osaka Int. Workshop on FNS, November 19-21, pp. 11-27, 1989
5. Reberšek, S., Stefanovska, A. and Vodovnik, L.: Some Properties of Spastic Ankle Joint Muscles in Hemiplegia, Med. & Biol. Eng. & Comput., 24: 19-26, 1986
6. Gottlieb, G.L., Myklebust, B.M., Penn, R.D., Agarwall, G.C.: Reciprocal Excitation of Muscle Antagonists by the Primary Afferent Pathway. Exp. Brain Res., 46: 454.456, 1982

Prof. Stanislav Reberšek, D.Sc.
Faculty of Electrical & Computer Engineering,
University of Ljubljana
61000 LJUBLJANA
Tržaška 25
Slovenia
Yugoslavia

IMPROVED VOLUNTARY GAIT PATTERN POST STROKE, FOLLOWING TREATMENT WITH THE MULTI-CHANNEL, INTRAMUSCULAR, MICROPROCESSOR-BASED FNS SYSTEM

Janis L. Jacobs, Katherine Barnicle, E. Byron Marsolais
VA Medical Center, Cleveland Ohio

ABSTRACT

Within a single case study design, we investigated the effects of FNS exercise/gait training on voluntary gait pattern post stroke, using a multi-channel, intramuscular, microprocessor-based FNS system. Subject A was age 46, and 4 years post left CVA, resulting in a gait pattern characterized by absence of normal swing hip/knee/ankle flexion of the paretic limb and the presence of three compensatory strategies. Ten muscles were implanted; individualized FNS exercises and gait training were provided 3-12 times/month for 9 months. Kinematic data quantified improvement: normal knee flexion at toe off, normal peak swing knee flexion, close to normal knee extension prior to heel strike, and resolution of prior compensatory strategies.

INTRODUCTION

Stroke is the number one cause of neurologic disability and second only to arthritis as the overall cause of disability. Following conventional rehabilitation, over 70% of stroke patients demonstrate residual functional disability which interferes with mobility and self care. Development of more effective techniques which improve lower extremity function will improve the quality of life and reduce associated health care costs for stroke patients. Within a single case study design, we investigated the effects of FNS exercise/gait training on voluntary gait pattern post stroke, using a multi-channel, intramuscular, microprocessor-based FNS system.

METHODS AND MATERIALS

Subject description

Subject A was age 46 and 4 years post left CVA. His gait pattern was characterized by absence of the normal swing hip/knee/ankle flexion of the right paretic limb. He used three compensatory strategies: right swing circumduction, right pelvic elevation, and early left stance plantarflexion. According to clinical records, Subject A demonstrated this unchanged baseline gait pattern for over two years prior to admission into the research program.

Muscle implantation

Ten muscles were implanted with electrodes using local anesthesia and a hypodermic needle technique (Marsolais, 1986). Implantation was performed for those muscles exhibiting dysfunction in isolated movement control or in gait pattern movement. The muscles implanted for Subject A were: right long and short heads of biceps femoris, iliopsoas, gracilis, sartorius, tensor fasciae latae, vastus medialis and lateralis, anterior tibialis, peroneals, and gastrocnemius/soleus.

Equipment

Electrodes were constructed of 10-strand stainless steel Teflon-coated wire with the leads configured in a double helical coil around a polypropylene core (Scheiner, 1990). The leads exited the skin and connected to a portable stimulator which was based on a V40 (NEC) microprocessor. Preprogrammed activities such as walking and stair climbing as well as exercises could be selected from a menu by using a hand switch. A specialized computer program, Vortex (Borges, 1989), was developed to be used on a MicroVAX II to create FNS patterns. All implanted muscles could be stimulated in any combination and sequence.

Data collection

Video documentation was made using a Panasonic Industrial Camera and a SONY U-Matic Cassette Recorder. Kinematic data collection was performed using a video-based data acquisition system made by Motion Analysis Corporation. This system recorded three dimensional movement in space from markers placed on body landmarks. The analysis of data was performed with a SUN MicroSystems 4/110 Computer, using a program developed by Motion Analysis Corporation and customized by our laboratory. Data was collected at months 1, 5, and 9.

Preparatory Evaluation

Movement analysis, voluntary muscle function, FNS-driven and FNS-assisted muscle function were evaluated. Acceptable stimulation parameter ranges were determined. Using all this information, the first stimulation pattern was devised. The desired FNS-driven movement was tested for effectiveness, and the FNS pattern variables were adjusted as needed. All stimulation parameters were adjustable, except amplitude which was held constant at 20 mA (pulse width 0-150 micro secs; frequency 16-50 Hz). The FNS gait pattern was synchronized with the subject's gait using force sensing resistors by Interlink Electronics affixed to Sorbothane insoles.

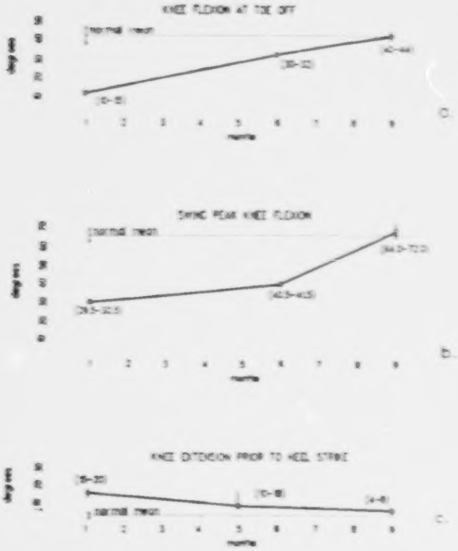


Figure 1. Mean improvement of three gait components (cadence 52 s/min) during a nine month period in which FNS exercise/gait training was provided 3-12 times/month. Normal mean values were taken from Winter (1987) at cadence, 75 s/min. The vertical bar at each data point represents range of variation, and range limits are given in parentheses. The vertical bar for normal represents standard deviation (Winter, 1987).

Treatment methods

Treatment was a systematic use of FNS to assist in or cue muscle contraction in normal combinations and sequences. Treatment was provided 3 to 12 times per month for 9 months. FNS treatment of stroke was performed simultaneously at three levels. Level 1 was FNS-driven exercise to improve strength, endurance, and coordination of muscle or groups of muscles. Level 2 was the FNS-driven functional movement of walking. Level 3 was FNS and voluntary movement integrated to retrain coordination of complex movements.

RESULTS

The video record of the gait pattern for Subject A documented an improvement of the overall gait pattern from right swing circumduction (prior to treatment) to voluntary hip/knee/ankle flexion during swing (post treatment). Results for Subject A can be divided into two categories: 1)improvements of three gait components (Fig. 1) and 2)increases beyond the normal movement pattern for two gait components (Fig. 2). The plotted data in Figures 1 and 2 were collected using the video-based data acquisition system and obtained by calculating the mean of three gait cycles within a single walking trial. The vertical bar at each data point indicates range of variation; range limits are given in parentheses.

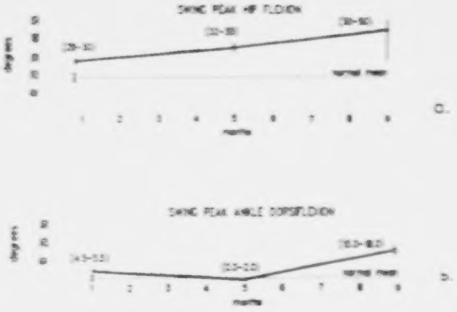


Figure 2. Mean increase beyond normal for two gait components, with all conditions as in figure 1.

Improvements in swing phase knee flexion and extension (fig. 1). Swing phase knee flexion improved to normal movement excursion both at toe off (42°) and at peak knee flexion (67°). See Figure 1a and b. Swing phase right knee extension prior to heel strike improved from 18° to 7° of right knee flexion immediately prior to heel strike (Fig 1c).

Increases beyond normal for swing hip and ankle flexion (fig. 2). Prior to treatment, swing phase hip flexion occurred in conjunction with a pendular motion of the right leg as a straight unit circumducting around the hip joint. After FNS exercise/gait training, hip flexion occurred in conjunction with a more normal hip/knee/ankle flexion movement. However, post-treatment hip and ankle flexion were performed beyond normal range by 22° and 14°, respectively.

In determining the meaning of the changes in gait pattern from month 1 to month 9, one may compare the range of variation on a given test date with the magnitude of change between month 1 and month 9 test dates. The vertical bar at each data point represents range of variation, and range limits are given in parentheses. In Figure 1 the ranges of variation for each test date are relatively small compared with the large changes between months 1 and 9 for each gait component. With small ranges of variation and large improvements, we can suggest that the improvements are meaningful.

In Figure 2 the range of variation of swing hip flexion at month 9 was from 30° to 50°, a large variation relative to the smaller increase in mean flexion from months 1 to 9. The large variation of swing hip flexion raises questions regarding the meaning of the data. These questions are addressed below. For ankle dorsiflexion the ranges of variation at months 1 and 9 were small in comparison to the increase in dorsiflexion from months 1 to 9; we can suggest that the increase is meaningful.

In summary, after FNS movement retraining, at a cadence of 52 steps/min, the subject demonstrated for voluntary gait right swing: normal right swing knee flexion throughout swing phase, close to normal right knee extension prior to heel strike, increased right swing hip and ankle flexion, resolved pelvic hiking, resolved circumduction, and resolved early contralateral stance plantarflexion. Without the FNS system, and at faster cadences, the subject still required verbal and tactile cues to perform the improved movement pattern described above.

DISCUSSION

Subject A's kinematic data indicate an overall improvement in gait pattern. However, swing peak hip and ankle flexion increased beyond normal. It is important to note the large variation (20°) of swing peak hip flexion at month 9. The large variation at month 9 could mean that the change from month 1 to 9 is not meaningful and is likely due to subject range of variation. However, no other gait component showed such range of variation; and in fact, this component, peak swing hip flexion, did not show a large range of variation at month 1. The reason for the large range of variation seen exclusively for peak hip flexion at month 9 only, could be related to the process of motor learning. The subject was attempting to change from a circumducted swing phase pattern in month 1 to a normal hip/knee/ankle flexion pattern in month 9. This subject may have found over time, that his newly learned swing phase knee flexion was inconsistent. To compensate for the possibility of stubbing his toe and falling, he may have adopted the increase beyond normal of swing hip and ankle flexion, finding the increased ankle dorsiflexion to be consistently useful and the increased hip flexion to be useful only on occasion, resulting in the large range of variation at month 9.

The improved gait demonstrated by Subject A indicates the importance of further study of the use of FNS as a movement re-training tool and as an assistive device. Two major difficulties arise in considering a formal study of the efficacy of any treatment for the spastic subject. First, it is difficult to measure changes in motor control for the neurologically impaired. Secondly, it is difficult to control for and/or predict outcome for the stroke subject who may exhibit spontaneous recovery of motor function. Nevertheless, it may be worthwhile to investigate the efficacy of FNS for the acute stroke patient. Early use of FNS post-stroke may prevent muscle atrophy, prevent development of abnormal movement patterns, and preserve joint integrity.

ACKNOWLEDGEMENT

This research was funded by the Rehabilitation Research and Development Service of the Department of Veterans Affairs.

We thank Peter Samame for kinematic data collection and reduction, Rockney Shepheard for figure preparation, and Carole Kantor for editing and preparation of figures.

REFERENCES

Marsolais EB, Kobetic R: Implantation techniques and experience with percutaneous intramuscular electrodes in the lower extremities. J Rehab Res Dev 23(3):1, 1986.

Scheiner A: A double helix electrode for functional electrical stimulation. Proc of the 13th Annual RESNA Conference, 1990, pp 373-374.

Borges G, Ferguson K, Kobetic R: Development and operation of portable and laboratory electrical stimulation systems for walking in paraplegic subjects. IEEE Transactions On Biomedical Engineering 36(7):798-801, 1989.

Winter DA: The biomechanics and motor control of human gait. Waterloo, Ontario, Canada, University of Waterloo Press, Dana Porter Library, 1987.

Janis L. Jacobs, M.S., LPT
Coordinator, Clinical Research
Motion Study Laboratory, 151-W
V.A. Medical Center
10701 East Blvd.
Cleveland, Ohio 44106

18.6

EFFICIENCY OF ELECTRICALLY STIMULATED EXERCISE: NORMAL VS SCI

Joyce Campbell, Paul Meadows, Robert Waters, Charles Carter,
Cindy Wederich, Maria Evers, Cyndi Sabourin, Tina Zivec
Rancho Rehabilitation Engineering, Downey, CA
California State University, Long Beach, CA

ABSTRACT

The purpose of this paper is to present a preliminary comparison of the energetics of knee exercise in normal (N) and spinal cord injured (SCI) subjects. N performed maximal effort (MVC) (60 deg/s), submaximal voluntary (VOL) exercise (40% MVC) with open circuit spirometry and electrically stimulated (ES) exercise at 40% MVC, or the maximum tolerable ES. SCI subjects did the same ES protocol at 40% of maximum ES moment. Moment, velocity and position from the isokinetic device (LidoActive) and metabolic data (Sensormedics Horizon) were sampled by an IBM PC/AT. ES was generated by the IBM and blood lactate was sampled during rest, exercise and recovery (YSI Model 23L). VOL exercise was more efficient (EFF) than ES (27 vs 23%) and fatigue correlated with EFF. SCI subjects had higher lactate levels at lower work rates and were less EFF than N in ES (10 vs 23%). These results show the need for further study of the extent to which SCI muscle can be trained to be more EFF for ES function. This information may be useful to help SCI patients understand that ES systems of the present cannot replace the wheelchair.

INTRODUCTION

Electrical stimulation is a valuable clinical tool in the management of stroke, head trauma and spinal cord injury (SCI). For the patient with residual control, ES may improve VOL force generation and timing of muscle contraction through a variety of mechanisms. In the completely paralyzed individual muscle performance and function are dependent upon ES. Muscles must be called upon in the proper sequence and they must generate sufficient force to stabilize joints or to move a body segment. Muscle performance must be reproducible for repetitive activities such as walking and economical enough to be supported by the patient's energy reserves. Although there are new strategies on the horizon for sophisticated ES muscle control, the relative energy demand of ES movement is critical to the success of any system for walking. Previous studies have demonstrated the failure of orthoses and ambulatory aids for walking in complete paraplegia. Although the orthoses provided stability and young patients learned to walk with the devices, their use was discontinued at home because of the excessive energy demand (1-8).

ES systems offer the possibility of substitution for the loss of VOL control and the discontinuation of heavy, restrictive orthoses. Freedom of joint motion in walking has reduced the energy demand of when compared to the use of a locked orthosis (8-10). Early reports of ambulation with ES systems revealed that it is extremely costly when compared to normal values (11-14). It may be, however, more economical than the use of orthoses and weight bearing on the arms (13). Disuse and the shift in metabolic profile of muscle after SCI would predispose the paralyzed muscle to early fatigue and reduced EFF of exercise (15-17). ES activation of muscle also may be expected to result in a lower EFF of work and earlier fatigue than volitional exercise (18-22). The purpose of this paper is to present a preliminary comparison of the energetics of knee extension exercise in normal and SCI subjects.

METHODS

Normal subjects: Data collection included a 40 repetition maximum knee extension fatigue test at 60 deg/sec (Day 1), sub-maximal knee extension exercise at 60 deg/sec with open-circuit spirometry for continuous sampling of expired gases (Day 2), and ES knee extension exercise at the same velocity (Day 3). A visual feedback display guided exercise at 40% of MVC (MVC-60). ES exercise was at 40% of MVC-60 or at the maximum comfortable stimulus intensity.

SCI subjects: ES recruitment curves were used to select 40% of the maximum ES knee extension moment as the target for closed loop ES exercise following the same protocol as the normal subjects and the exercise was ended after a minimum of three minutes of steady-state. SCI subjects (T8 and T10 complete) were unable to feel the ES or VOL extend the knee, and the quadriceps were free of denervation. Because of the small sample sizes (6 N and 3 SCI subjects), only descriptive statistics are reported.

Instrumentation: An isokinetic exercise device (Loredan Biomedical, Davis, CA) measured angular position, velocity, and moment during knee exercise. Analog signals were sampled by an IBM PC/AT computer for calibration, gravity compensation and data acquisition. The IBM laboratory computer also was used for generation of ES and for all data management (23). Asymmetrical biphasic pulses, 300 µSec, at a frequency of 33pps were used. Amplitude was modulated to maintain the target moment within ± 2.0 Nm. A SensorMedics MMC Horizon metabolic cart (Yorba Linda, CA) analyzed expired gases and an ECG system telemetered heart rate. Metabolic information was provided to the IBM PC/AT system as real time data reports every 15 seconds. A YSI Model 23L lactate analyzer (Yellow Springs, Ohio) was used to sample blood lactate. Moment data were gravity compensated for use in the calculation of mechanical work for estimation of EFF from the relationship between metabolic and mechanical work.

RESULTS

VOL knee exercise at 40% of MVC-60 (43 ± 4%) resulted in an EFF of 27%. When oxygen uptake was corrected for resting, exercise was 45% efficient. VOL fatigue curve characteristics correlated with the EFF of exercise. Higher peak moments were associated with lower EFF (r=-.96) and lower fatigue correlated with higher EFF of submaximal exercise (r=-.91). Subjects varied in tolerance of isokinetic ES exercise and maximum ES moments ranged from 20 to 42% of MVC-60. This contributed to a lower rate of work during ES exercise (ES=25.1 ± 27.2 vs VOL=51.8 ± 10.9 Watts). The EFF of ES exercise was lower than VOL exercise (ES=23.0 ± 10.2% vs VOL=27.2 ± 3.9%). Peak moments generated during ES were correlated with lactate at the fifth minute after exercise (r=.94).

SCI subjects worked at a similar percent of muscle force generation capability (N=32.3% of MVC-60, SCI=38.4% of maximal ES contraction [MESC-60]). This resulted in significantly different work rates (N=25.1 vs SCI=8.8 Watts). Muscle fatigue precluded completion of the test protocol at higher ES exercise intensities in SCI subjects.

SCI subjects were less EFF and demonstrated higher exercise and recovery lactate levels while working at a similar percentage of maximal muscle performance as the N subjects, but at a work rate of 35% of N. SCI subjects worked at 59% of normal EFF when oxygen uptake was corrected for resting values (Figure 1). Neither hamstring nor hip adductor spasticity was visually observed during the exercise.

DISCUSSION

The lower EFF of ES versus VOL exercise observed in this sample is similar to previous findings in a sample of 23 N subjects, in which the differences between ES and VOL exercise were larger (p<.001) than in these 6 subjects (18). Preferential activation of fast glycolytic muscle fibers, geographical localization of contracting muscle, direct stimulation of the sympathetic fibers to intramuscular vasculature and stimulation at a fixed rate of 33 pps could contribute to reduced EFF of exercise (17,19,20-21,24-25). Strong correlations between EFF and VOL peak moment as well as the decrement in force production over 40 maximal efforts points to reduced EFF in subjects with a more glycolytic metabolic profile in the quadriceps (26-29). The relative inefficiency of these preliminary SCI subjects could be associated with disuse of muscle, a shift to a more anaerobic metabolism, unobserved elicitation of hamstring spasticity during the exercise, or other unknown factors. Higher lactate values, over resting, in SCI would support the more anaerobic nature of the exercise.

Although the knee extension exercise employed in this study does not simulate the concentric and eccentric quadriceps activity in standing and walking, the findings have clinical application to goal setting in complete SCI. It appears that ES is less efficient than volitional exercise and that paralyzed muscles in SCI are paying a greater energy penalty than N muscle during relatively low intensity exercise. The results of this, and other, studies point to the need for further investigation to determine the extent to which completely paralyzed muscle can be trained to produce greater force and to be more fatigue resistant as well as more metabolically efficient in order to support daily function. This information also may be useful to help SCI patients understand that ES systems of the present and near future cannot replace the wheelchair, but may be a tool to augment function from a wheelchair in the home and workplace.

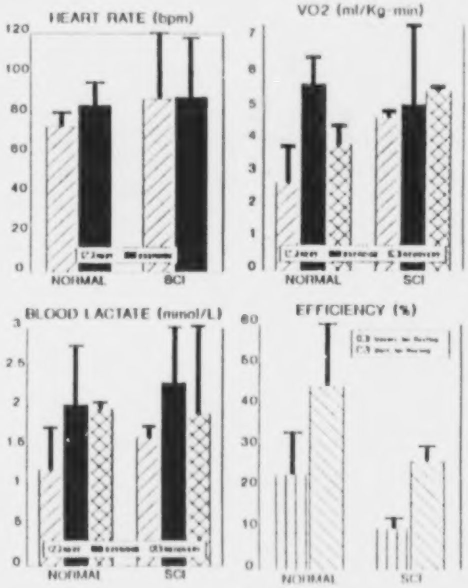


Fig 1. Heart rate, oxygen uptake, lactate and EFF in N vs SCI in ES knee exercise. N subjects worked at 32.9% MVC and SCI at 38.4% of max ES. SCI worked at lower work rate than N (8.8 vs 25.1 Watts).

ACKNOWLEDGEMENT

Funding for this research has been provided in part by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant No. H133A80042. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of NIDRR.

REFERENCES

1. Cerny K, Waters R, Hislop H, Perry J: Walking and wheelchair energetics in persons with paraplegia. Phys Ther 60:1133-1139, 1980.
2. Chantraine A, Crielaard JM, Onkelinx A, Pirnay F: Energy expenditure of ambulation in paraplegics: effects of long term use of bracing. Paraplegia 22:173-181, 1984.
3. Clinkingbeard JR, Gersten JW, Hoehn D: Energy cost of ambulation in traumatic paraplegia. Am J Phys Med 43:157-165, 1964.
4. Gordon EE, Vanderwalde H: Engegy requirements in paraplegic ambulation. Arch Phys Med Rehabil 37:276-285, 1956.

5. Huang C-T, Kuhlemeier KV, Moore NB, Fine PR: Energy cost of ambulation in paraplegic patients using Craig-Scott braces. Arch Phys Med Rehabil 60:595-600, 1979.
6. Merkel KD, Miller NE, Westbrook PR, Merritt JL: Energy expenditure of paraplegic patients standing and walking with two knee-ankle-foot orthoses. Arch Phys Med Rehabil 65:121-124, 1984.
7. Rosman N, Spira E: Paraplegic use of walking braces: survey. Arch Phys Med Rehabil 55:310-314, 1974.
8. Waters RL, Lunsford BR: Energy cost of paraplegic locomotion. J Bone Joint Surg[Am] 67:1245-1250, 1985.
9. Campbell J, Waters RL, Perry J: Simulated Knee and Ankle Contracture: Demands in Walking. Physiother Can 37:6 (Suppl), 1985.
10. Waters RL, Yakura JS, Adkins R, Barnes G: Determinants of Gait Performance Following Spinal Cord Injury. Arch Phys Med Rehabil 70:811-818, 1989.
11. Edwards BG, Lew RD, Marsolais EB: Relative Energy Costs of Long-Leg-Brace and FNS Ambulation. Proc 9th Annu RESNA Conference, Minneapolis, MN, June 1986, pp 322-324.
12. Isakov E, Mizrahi J, Graupe D, Becker E, Najenson T: Energy Cost and Physiological Reactions To Effort During Activation Of Paraplegics By Functional Electrical Stimulation. Scand J Rehab Med Suppl 12:102-107, 1985.
13. Marsolais EB, Edwards BG: Energy Costs of Walking and Standing with Functional Neuromuscular Stimulation and Long Leg Braces. Arch Phys Med Rehabil 69:243-249, 1988.
14. Miller PC, Kobetic R, Lew RD: Energy Costs of Walking and Standing Using Functional Electrical Stimulation. Proc 13th Annu RESNA Conference, Washington, D.C., June 1990, pp 155-156.
15. Grimby G, Broberg C, Drotkiewska I, Drotkiewski M: Muscle fiber composition in patients with traumatic cord lesion. Scand J Rehabil Med 8:37-42, 1976.
16. Lieber RL: Skeletal Muscle Adaptability. II: Muscle Properties Following Spinal-Cord Injury. Develop Med Child Neurol 28:533-542, 1986.
17. Rall JA: Energetic aspects of skeletal muscle contraction: Implications of fiber types. Exerc Sports Sci Rev 13:33-74, 1985.
18. Campbell J: Efficiency of Volitional Versus Electrically Evoked Knee Extension Exercise. Proc 10th Annu RESNA Conference, San Jose, CA, 1987, pp 648-650.
19. Collins SR, Glaser RM: Comparison of aerobic metabolism and cardiopulmonary responses for electrically induced and voluntary exercise. Proc RESNA 8th Annu Conf, Memphis TN, 1985, pp 391-393.
20. Duran WN, Rnekin EM: Influence of sympathetic nerves on oxygen uptake of resting mammalian skeletal muscle. Am J Physiol 231:529-537, 1976.
21. Mortimer JT, Peckham PH: Intramuscular electrial stimulation. In: Fields WS, Leavitt LA [Ed]: Neural Organization and Its Relevance to Prosthetics. New York, Intercontinental Medical Book Corp, 1973.
22. Phillips CA: Functional Electrical Stimulation and Lower Extremity Bracing for Ambulation Exercise of the Spinal Cord Injured Individual: A Medically Prescribed System. Phys Ther 69:842-849, 1989.
23. Meadows PM, McNeal DR: A Four-Channel IBM PC/AT Compatible Biphasic Pulse Generator for Nerve Stimulation. IEEE Trans Biomed Eng 36:802-804, 1989.
24. Edstrom L, Kugelberg E: Histochemical composition, distribution of fibres and fatiguability of single motor units. J Neurol Neurosurg Psychiat 31:424-433, 1968.
25. Rack PMH, Westburn DR: The effects of length and stimulus rate on tension in the isometric cat soleus muscle. J Physiol 204:433-460, 1969.
26. Ivy JL, Withers RT, Van Handel PJ, Elger DH, Costill DL: Muscle respiratory capacity and fiber type as determinants of the lactate threshold. J Appl Physiol 48:523-527, 1980.
27. Ivy JL, Sherman WM, Miller JM, Maxwell BD, Costill DL: Relationship between muscle O2 and fatigue curing repeated isokinetic contractions. J Appl Physiol 53:470-474, 1982.
28. Komi PV, Tesch P: EMG frequency spectrum, muscle structure and fatigue during dynamic contractions in man. Eur J Appl Physiol 42:41-50, 1979.
29. Thorstensson A, Karlsson J: Fatiguability and fibre composition of human skeletal muscle. Acta Physiol Scand 98:318-322, 1976.

Joyce M. Campbell, Ph.D.
Rancho Rehab. Engineering Program
7503 Bonita Street - Bonita Hall
Downey, CA 90242

CHANGES IN RECRUITMENT CURVES OF NERVE HELIX ELECTRODES WITH TIME FOLLOWING IMPLANTATION AND KNEE ANGLE

18.7

Donald R. McNeal,[1] Lucinda L. Baker,[2] and William F. Agnew[3]
[1]Rancho Rehab Engineering Program, Downey, CA
[2]University of Southern California, Los Angeles, CA
[3]Huntington Medical Research Institute, Pasadena, CA

ABSTRACT

Recruitment characteristics of four helix electrodes implanted around the tibial nerves of two cats were measured at 4-week intervals for 36 weeks. The recruitment curves were less variable after the first 20 weeks, but they continued to fluctuate from one recording session to the next. With all four electrodes, the stimulation values required to produce a given level of muscle tension at 36 weeks was about half of that required at 2 weeks; i.e., thresholds decreased significantly with time. Ranging the knee shifted the recruitment curves and resulted in higher required stimulation values as the knee was flexed. Since the electrodes were located in the popliteal space behind the knee, these changes were likely caused by alterations in the shape and orientation of the electrode, nerve and surrounding tissue. The changes in recruitment noted above present additional challenges for engineers attempting to design controllers for functional neuroprosthetic systems.

INTRODUCTION

The feasibility of functional control of paralyzed extremities has been demonstrated in recent years (3,4,5). The present need is for system components (multichannel stimulators, electrodes and sensors) that can be safely implanted inside the body and can function effectively for many years.

This paper presents new data on the recruitment properties of nerve bipolar helix electrodes that were chronically implanted in cats. Recruitment data were measured at four week intervals for 36 weeks to document any changes in recruitment properties following implantation. A second purpose of this study was to determine the effect on the recruitment curves of ranging the knee from full extension to 90° of flexion.

METHODS

The nerve electrode used in this study was a bipolar helix electrode designed and fabricated by the Huntington Medical Research Institutes, Pasadena, California (1). Two platinum ribbon electrodes, 1 mm in width and separated by 7 mm, were mounted inside 2 mm diameter helical coils made of silicon rubber. A special tool was used to assist in wrapping the helical coils around the nerve.

One electrode was placed on the right and one on the left posterior tibial nerves in two cats. Male adult cats were preanesthetized with Ketamine (25 mg/kg) followed by Surital (2.5%, to effect) with transition to a 1:1 mixture of nitrous oxide and oxygen and 0.5 to 0.75% Halothane. End-tidal pCo_2 was monitored continuously with a Beckman CO_2 analyzer. A midline scalp incision was made and a transcutaneous, modified Cannon connector was fixed to the skull using stainless steel screws and cranioplasty. The two helical electrodes and cables attached to the transcutaneous connector were then tunneled subcutaneously, using a Teflon guide tube, to the lumbosacral area. The popliteal fossa was exposed, and the electrode and cable tunneled via the sciatic notch to the area of the right and left posterior tibial nerves. The helical electrodes were applied to the nerves by means of a forceps-like electrode applicator. Postoperatively the animals were placed in a temperature-regulated recovery cage to recover from the effects of anesthesia.

Testing was performed at four-week intervals. The anesthetic procedure used was similar to that described above. Animals were placed prone in a frame designed to stabilize their position and measure plantarflexion moments at the ankle. The hip and knee were extended, and the ankle was held at 90° of flexion by strapping the paw to an adjustable cantilever beam instrumented with strain gauges. Signals from the strain gauges were amplified, digitized and transferred to an IBM AT personal computer. The computer controlled a digital stimulator (Dagan Omni Pulse 9200) and a color graphics adaptor board for online data display.

A recently developed software program was used for data collection (7). Recruitment data were obtained by fixing the duration of a monophasic constant-current pulse and varying the pulse amplitude over the range between threshold and maximum recruitment. Isometric muscle twitches were used to minimize fatigue. The peak value of the resulting twitch was recorded with the corresponding value of the pulse amplitude and displayed on the color monitor. The software had five menu-selectable subroutines which are briefly described below:

- Calibration: Known weights were applied to the force transducer to calibrate the system prior to each session.
- ID Data: Identifying data for the animal, electrode, electrode location, session number, etc. were input using this routine. The selection of either pulse amplitude or duration as the modulating parameter and specification of the other parameter was done in this routine.
- Determine Max Twitch: The maximum twitch response was found by averaging the peak twitch at supramaximal stimulation over a series of repeated twitches. Nominally, 10 twitches at a frequency of .3 Hz were used.

- o Approximate Curve: Normalized tension (peak twitch tension divided by the average maximum twitch tension) was displayed on a graph of normalized tension versus the value of the modulating amplitude. Enough points were generated to approximate the curve (generally 3-6 points were sufficient), then a linear interpolation routine was used to select ten values of the modulating parameter to generate muscle tension in approximately 10% steps from 5 to 95% of the maximum twitch tension.

- o Generate Recruitment Curve: The ten values of the modulating parameter determined in the previous routine were used to generate the final recruitment curve. In this study, each point was repeated 5 times at 3 second intervals, so the time required for generating one curve was 2.5 minutes. The computer randomized the order in which values of the modulating parameter were presented. Points were displayed on the monitor as they were generated.

The reproducibility of the data was tested in each animal be repeating one curve (pulse amplitude modulation at 100 µs pulse duration) eleven times within a one-hour period. During this sequence, the animals were twice removed from the test apparatus and then repositioned. A quantitative measure of the change in successive curves was calculated as follows: the percentage changes in pulse amplitude at normalized moments of 10, 20, ..., 80% were averaged to obtain a single number, which we called the relative difference. A negative relative difference means that the recruitment curve has shifted to the left (in the direction of lower stimulation values). When generation of the recruitment curve was repeated without moving the animal, the mean and standard deviation of the relative difference was 1.3% ±1.0 (N=56). When the animal was moved and repositioned, the corresponding values were 6.7% ±5.2 (N=14). These results indicated that recruitment curves were very reproducible within a session, but that comparison of curves from different sessions were subject to some error because of repositioning the animals.

RESULTS

Recruitment data were initially measured two weeks after implantation, then at four week intervals (4, 8, 12, ... weeks following implantation). Recruitment curves (variable amplitude at a pulse duration of 100 µs) are shown in Fig. 1 for each of the four electrodes at 2 weeks (Fig. 1a) and 36 weeks (Fig. 1b). It can be seen that the stimulation values required at 36 weeks were significantly lower (about half) than the stimulation values required at 2 weeks.

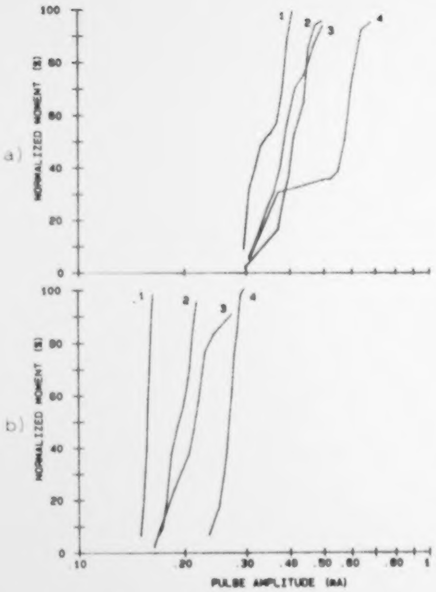


Fig. 1. Recruitment curves (100 us pulse duration) for the four electrodes recorded at a) 2 weeks and b) 36 weeks following implantation. Electrodes 1 and 2 were implanted in one animal; electrodes 3 and 4 in the second.

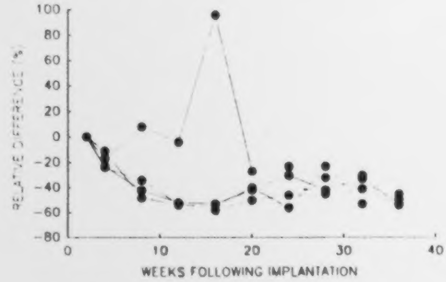


Fig. 2. Relative differences between recruitment curves of the four electrodes in Week 2 and succeeding weeks. See text for definition of relative difference.

The time history of the change in recruitment curves during the 36 weeks is shown in Fig. 2. Three of the electrodes followed a similar path; namely, stimulation values decreased during the first 16 weeks to approximately one-half of the values required at 2 weeks. Beyond 16 weeks, there was fluctuation in the recruitment curves, but no significant trend. The fourth electrode followed a very dissimilar path during the first 16 weeks; remaining close to the values recorded in Week 2 but then shifting to a significantly higher value in Week 16. From Week 20 on, the relative differences for this electrode were similar to those of the other three electrodes. The relative differences in Week 36 (relative to Week 2) are about -50%.

In Week 36, after the recruitment curves had stabilized somewhat, recruitment curves were measured at knee angles of 45 and 90° in addition to full extension (0°). The results for one electrode are shown in Fig. 3. It can be seen that the recruitment curve shifts to the right (higher stimulation values) as the knee is flexed. A similar change was observed in the other three electrodes.

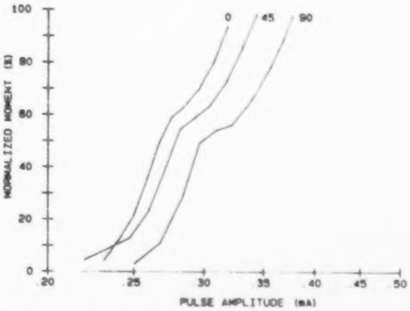


Fig. 3. Recruitment curves (100 us pulse duration) for one electrode at three knee angles (0, 45, 90°).

DISCUSSION

The recruitment data for the bipolar helix electrode were similar to data previously obtained with other types of nerve electrodes (2,6). Gorman and Mortimer presented recruitment data for a monopolar loop electrode with and without a cuff backing and showed that stimulus levels with the cuff backing were much lower than those for the loop electrode without backing (2). Stimulus levels for the bipolar helix electrode fell between the values reported with and without the cuff backing, as would be expected since the helix electrode has only a partial insulating backing. Recruitment data for a bipolar cuff electrode with 1x2 mm platinum disks placed inside the cuff (Avery Laboratories, Farmingdale, NY) were obtained from chronic cats by McNeal et al (6). In those experiments, the stimulation ranges at comparable pulse durations were slightly higher than in the current study.

No one has previously reported temporal changes in recruitment curves of implanted nerve electrodes. It was interesting that recruitment curves for all four electrodes in this study shifted toward lower stimulation values after 20 weeks, and that all stimulation levels at Week 36 were about half of the values recorded at Week 2. More electrodes would have to be tested, however, to determine whether this is a consistent trend.

Even months after implantation, recruitment curves were found to fluctuate from one recording session to the next. This was somewhat surprising in that we had expected that the recruitment characteristics would be more stable several months after implantation. These temporal fluctuations and the changes noted as the knee was flexed will present difficulties for engineers attempting to design controllers for functional neuroprosthetic systems.

ACKNOWLEDGEMENT

Funding for this research has been provided in part by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant No. G008720075. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of NIDRR.

REFERENCES

1. Agnew W.F., McCreery D.B., Yuen T.G.H. and Bullara L.A.: Histologic and physiologic evaluation of electrically stimulated peripheral nerve: Considerations for the selection of parameters. *Ann. Biomed. Eng.*, 17:39-60, 1989.

2. Gorman P.H. and Mortimer J.T.: The effect of stimulus parameters on the recruitment characteristics of direct nerve stimulation. *IEEE Trans. Biomed. Eng.*, 30(7):407-414, 1983.

3. Keith, M.W., Peckham P.H., Thrope G.B., Stroh K.C., Buckett J.R., Kilgore K.L. and Jatich J.W.: Implantable functional neuromuscular stimulation in the tetraplegic hand. *J. Hand Surg.*, 14A(3):524-530, 1989.

4. Kralj A., Bajd T., Turk R., Krajnik J. and Benko H.: Gait restoration in paraplegic patients: A feasibility demonstration using multichannel surface electrode FES. *J. Rehab. R&D*, 20(1):3-20, 1983.

5. Marsolais E.B. and Kobetic R.: Functional electrical stimulation for walking in paraplegia. *J. Bone Joint Surg.*, 69A(5):728-733, 1987.

6. McNeal D.R.. Baker L.L. and Symons J.: Recruitment data for nerve cuff electrodes: Implications for design of implantable stimulators. *IEEE Trans. Biomed. Eng.*, 36(3):301-308, 1989.

7. Tu W., McNeal D.R. and Baker L.L.: A computerized system to generate recruitment data for neuromuscular electrodes. In: *Proc. 11th Annu. Int. Conf. IEEE/EMBS*, Seattle WA, 1989, pp. 973-974.

Donald R. McNeal, Ph.D.
Rancho Rehab. Engineering Program
7503 Bonita Street - Bonita Hall
Downey, CA 90242

18.8 USE OF THRESHOLD CURRENT CHANGES AS AN INDEX OF RESPONSIVENESS AND FATIGABILITY IN PARALYZED MUSCLE DURING FUNCTIONAL NEUROMUSCULAR STIMULATION

Andrew J. Kuntzman, Roger M. Glaser, Mary M. Rodgers, and Randy A. Shively, and Bertram N. Ezenwa
Department of Anatomy and Department of Rehabilitation Medicine & Restorative Care, Wright State University School of Medicine, Veterans Affairs Medical Center, and Miami Valley Hospital, Dayton, Ohio

ABSTRACT

Functional neuromuscular stimulation (FNS) of paralyzed muscle has been utilized to improve the rehabilitation of spinal cord injured (SCI) patients. As an adjunct to the long-term exercise training protocols conducted within our laboratory, a total of 91 isometric evaluations (pre- and post-tests) of quadriceps muscle strength and endurance were completed on 29 subjects. This test consisted of up to 40 repetitive contractions (2/min) at a maximum force of 15 Kg or maximum FNS current of 150 mA. Several patterns of muscle fatigue characteristics emerged and muscles were classified as "stronger," "intermediate," and "weaker." Within the three subgroups it was noted that changes in threshold current provided an index of muscle responsiveness and fatigability. These data may contribute to a better understanding of muscle performance and FNS current parameters to enable more precise control of paralyzed muscle.

INTRODUCTION

Functional neuromuscular stimulation (FNS) has been studied as a method of restoring purposeful movements to paralyzed muscles of spinal cord injured (SCI) individuals. However, preliminary studies of stimulation current vs muscle performance have shown that FNS causes marked and progressive fatigue of paralyzed muscle (Kuntzman et al., 1990b). Additional FNS studies indicate that fatigue patterns differ in SCI subjects according to the strength and FNS responsiveness of the paralyzed muscle. The purpose of this study was to identify stimulation current/muscle force characteristics that further differentiate muscle responsiveness and fatigability. These data may ultimately be used to construct an index that would predict FNS performance of paralyzed muscle from a series of submaximal contractions.

METHODS

The instrumentation used to conduct this study was described by Ezenwa et al.(1989) and the protocol was described by Kuntzman et al. (1990a). A group of 28 SCI subjects and one able-bodied control subject participated in this institutionally-approved protocol. A total of 91 isometric tests were conducted to determine the reliability of measurement. Surface electrodes were used to administer ramped FNS current from 0 to a maximum of 150 mA in 15 sec, or to a level that induced a maximum contraction force of 147 N; FNS current was then ramped down to 0 mA in 15 sec or less. The quadriceps muscles were stimulated every 30 sec for 40 contraction trials or until the muscle fatigued to 25% of its original peak force output. For this study, contraction threshold current (the initiation of force indicative of muscle contraction) was defined as 3.67 N (2.5% of 147 N). Spasticity of muscles in some subjects during the initial phase of contraction prohibited a lower threshold force definition (Rodgers et al., 1990). Data were generally collected from the right leg, except for those subjects who exhibited extreme spasticity, necessitating use of the left leg. To determine reliability of the data, the test was repeated on several subjects. At least 5 days were allowed between tests or following other FNS procedures.

RESULTS

Three major patterns emerged from the 28 SCI subjects tested: 1) 23 of the tests indicated 10 stronger subjects who achieved the targeted 147 N force on all 40 trials with FNS currents of less than 150 mA, 2) 15 of the tests indicated 9 weaker subjects who were not capable of achieving the targeted force of 147 N even though they received the maximal current of 150 mA, and 3) 52 of the tests indicated that the remaining 9 subjects were of

TABLE 1. Threshold Currents (mA) Required for First and Last Contraction Trials*

Stronger Subjects				Weaker Subjects			
Subject	First	Last	Difference	Subject	First	Last	Difference
A	47	58	11	M1	46	102*	56
B1	16	43	27	M2	46	108*	62
B2	29	73	44	M3	47	87*	40
B3	34	53	19	N	42	78*	36
B4	48	77	29	O	52	97	45
C1	23	39	16	P	78	118	40
C2	29	33	4	Q1	80	118	38
D1	32	56	24	Q2	95	123	28
D2	32	58	26	Q3	82	130	48
D3	33	46	13	R1	33	100	67
D4	28	52	24	R2	42	88	56
D5	30	43	13	S	68	124	56
D6	25	47	22	T	56	94	38
E1	33	63	30	U	47	72*	25
E2	43	64	21	V	51	97	46
E3	44	73	29				
F1	45	74	29				
F2	48	66	18				
G	58	64	6				
H1	53	62	9				
H2	44	68	24				
I	33	58	25				
J	41	57	16				
$\bar{X}$	37	58	21		57	102	45
±SE	2.2	2.5	1.9		4.7	4.5	3.1

*Subjects achieved fewer than 40 trials (20-35).

The numeral following the subject letter ID indicates the repeated tests.

intermediate strength. These subjects initially were capable of achieving a force of 147 N, but then exhibited decreased force output in spite of the FNS current increasing to the maximum level.

Table 1 provides the threshold currents required to induce a trace contraction of 3.67 N during the first and final contraction trials, as well as differences in the threshold current levels due to fatigue. It was found that the difference in threshold current required to induce a trace contraction during the first and last trial was smaller in stronger subjects and larger in weaker subjects. The subjects with intermediate strength had threshold currents which were between the stronger and weaker subjects. Data from the 52 tests on the intermediate subjects are not included in Table 1.

Although not universally true, many of the threshold values cited in Table 1 were remarkably similar between tests for each of the subjects who were tested more than once. For example, subject D required threshold currents of 32, 32, 33, 28, 30, and 25 mA for the initial threshold contraction during the six tests.

DISCUSSION

Data collected from 90 isometric tests involving 28 SCI subjects and collected over a 19-month time span indicate that several trends existed in the strength and fatigue patterns of paralyzed quadriceps muscle, as well as the magnitude of FNS current required. Subjects with stronger muscles were capable of achieving the targeted peak force level with a series of submaximal stimuli (less than 150 mA). They also required a lower current level for a given force output (Kuntzman, et al., 1990a). The progressive nature of muscle fatigue was demonstrated when each succeeding contraction trial required a slightly higher current level.

The stronger subjects exhibited threshold contraction at mean currents of 37 ± 2.2 and 58 ± 2.5 mA for the for and last trial, respectively (Table 1). The mean difference between the threshold current required for the first and last of the 40 trials was 21 ± 1.9 mA (range = 4 to 44 mA). In contrast, the subset of subjects with weaker muscles never achieved the targeted force even though they were stimulated with the maximum of 150 mA. In these subjects, fatigue was evidenced by the drop in force level with each subsequent trial. These weaker subjects exhibited threshold contraction at mean currents of 58 ± 4.7 and 102 ± 4.5 mA for the for the first and last trial, respectively (Table 1). Mean difference between the FNS threshold current required for the first and last contraction was 45 ± 3.1 mA (range = 25 to 67 mA). It thus appears that the increase in threshold current during repetitive FNS-induced contractions can be used as an index of muscle responsiveness and fatigue.

It should be noted that one able-bodied control subject was tested for comparison with the SCI subjects. Threshold contraction currents for this control subject were 36 mA for the first trial and 48 mA for the 40th trial, a difference of only 12 mA. It was also observed that the initial threshold current of 36 mA was very similar to the mean value for the stronger SCI subjects (37 ± 2.2). In contrast, the weaker SCI subjects had an initial threshold current value of 58 mA. Therefore, threshold current tends to vary inversely with the performance capability of the muscle and directly with the state of muscle fatigue.

For subjects who were tested more than once, the threshold levels for each contraction trial tended to be remarkably similar. Given the physiological variability in humans from one day to the next, this finding indicates a high level of reliability for the threshold current parameter.

In conclusion, FNS current requirements clearly change with the muscle responsiveness and fatigue. Additional research needs to be conducted on decrements in muscle performance during FNS-induced activities and FNS parameters needed to maintain activities. As the mechanisms of fatigue are better understood, FNS systems can be better designed to enhance the the precision of movement, as well as the functional capability of SCI individuals.

ACKNOWLEDGEMENT

This research was supported in part by the Rehabilitation Research and Development Service of the U.S. Department of Veterans Affairs.

REFERENCES

Ezenwa, B.N., Glaser,R.M., Almeyda, J. and Figoni, S.F.. Force-Current Measurement System for Evaluating Muscle Performance During Functional Neuromuscular Stimulation. Proc. RESNA 12th Annual Conf., New Orleans, LA. 179-180. 1989.

Kuntzman, A.J., Glaser, R.M., Shively, R.A., Rodgers, M.M., and Ezenwa, B.N. Muscle Fatigue Characteristics with FNS-Induced Contractions. Proc. RESNA 13th Annual Conf., Washington, DC. 161-162. 1990.

Kuntzman, A.J., Rodgers, M.M., Glaser, R.M., Shively, R.A., and Ezenwa, B.N. Functional Neuromuscular Stimulation Threshold Elevation with Fatiguing Paralyzed Muscle. Proc. Intl. Soc. Electrophysiol. Kinesiol., Baltimore, MD, August, 1990.

Rodgers, M.M., Kuntzman, A.J., Glaser, R.M., Shively, R.A., and Ezenwa, B.N. Characteristics of Functional Neuromuscular Stimulation-Induced Spasticity in Spinal Cord Injured Subjects. Proc. Intl. Soc. Electrophysiol.. Kinesiol., Baltimore, MD, August, 1990.

Andrew J. Kuntzman, Ph.D.
Department of Anatomy
School of Medicine
Wright State University
Dayton, OH 45435

TRAINING IN REHABILITATION ENGINEERING/TECHNOLOGY

Paul N. Hale, Jr., John R. Schweitzer and Frank D. Puckett
Center for Rehabilitation Science and Biomedical Engineering
Louisiana Tech University
Ruston, LA 71272

Abstract

In October of 1990, our University received its second three-year grant from the Rehabilitation Services Administration to provide education and training in rehabilitation engineering/technology at the regional and national levels. Under this grant, engineers, technologists, counselors, therapists and educators will have an opportunity to interact with clinical professionals in a comprehensive rehabilitation engineering center and study state-of-the-art technology applied to the needs of persons with disabilities.

Background

Historically, the Rehabilitation Services Administration (RSA) has funded long-term training programs designed to:

1. increase the supply of personnel available for employment in public and private rehabilitation and independent living rehabilitation of individuals with physical and mental disabilities, especially those with the most severe disabilities; and

2. maintain and upgrade basic skills of personnel employed as providers of vocational, medical, social, or rehabilitation services to individuals with severe disabilities.

In 1987, RSA added Rehabilitation Engineering as one of their targeted programs for long-term training. Four programs received funds to conduct training in rehabilitation engineering/technology during the years 1987-1990. These efforts proved quite successful and in 1990, through a new Request for Proposals, four grants were awarded to the following institutions/facilities:

Rehabilitation Engineering Teaching and Training Program
California State University at Sacramento
6000 J Street
Sacramento, CA 95819-6019
Contact: Rory Cooper, Ph.D., (916)278-6916
(Program emphasis: Masters degree in biomedical engineering, certificate in rehabilitation technology)

Rehabilitation Engineering/Technology Training Project
Illinois Institute of Technology
Department of Psychology
3101 South Dearborne
Chicago, IL 60616
Contact: Chow Lam, Ph.D., (312)567-3514
(Program emphasis: Training of rehabilitation counselors for specialization in rehabilitation technology)

Rehabilitation Engineering Training Program
University of Virginia
P. O. Box 3368, University Station
Charlottesville, VA 22903
Contact: Clifford Brubaker, Ph.D., (804)977-6730
(Program emphasis: Masters degree in biomedical engineering with specialization in rehabilitation engineering)

Training in Rehabilitation Engineering/Technology
Center for Rehabilitation Science
and Biomedical Engineering
P. O. Box 3185
Louisiana Tech University
Ruston, LA 71272
Contact: Paul N. Hale, Jr., Ph.D., (318)257-4562
(Program emphasis: (a) Graduate education in biomedical engineering
and (b) Professional training for rehabilitation personnel)

Objectives

The training grant awarded to our rehabilitation engineering center has the following program objectives:

1. To increase knowledge regarding the rehabilitation engineering/technology services required under the Rehabilitation Acts Amendments of 1986.

2. To prepare engineers/technologists to provide rehabilitation engineering services.

3. To provide inservice training on rehabilitation technology for university faculty in rehabilitation counselor training programs.

4. To sponsor graduate education for engineers studying to work in the field of rehabilitation.

5. To acquaint rehabilitation management and service providers with the issues of developing and marketing rehabilitation technology.

6. To develop model curriculum for training engineers/technologist and service providers.

Results

In recent years, there has been a significant increase in the number and variety of rehabilitation devices and equipment. Consumer access to this technology and the funds to purchase them have also increased, allowing a person with a disability greater independence in life and work. Through both short-term and long-term training, our Center is providing professionals with a unique opportunity to learn about this technology, assessment procedures and information about its appropriate application.

Discussion

Since 1978, our rehabilitation engineering center has received funds from the state rehabilitation services agency to conduct state-wide services in rehabilitation engineering/technology. Today our Center is providing citizens in the state with services in mobility, seating and positioning, independent living, workplace modification and accessibility, adaptive driving, augmentative communication, and a dormitory for college students with severe disabilities. In addition, the Center has an assistive devices information service and two field-based rehabilitation engineers who are providing rehabilitation engineering/technology services to rehabilitation clients across the state.

Our training project has three major components:

1. Graduate education (Master's level training in biomedical engineering)

2. Technology awareness training for rehabilitation counselors, supervisors and university-based rehabilitation educators.

3. Clinical skill training in assessments for adaptive driving, augmentative communication, and rehabilitation technology field services.

Graduate Education (Masters Degree)

In the three-year grant period, our program will train eight masters-level engineers in the application of rehabilitation technology. This is a thirty-six semester hour, non-thesis degree program and includes a summer internship in a rehabilitation setting. A typical program would include the following courses:

Rehabilitation of Persons with Physical Disabilities (3)
Electronic Devices for Rehabilitation (3)
Rehabilitation Engineering I (3)
Rehabilitation Engineering II (3)
Rehabilitation in the Aging (3)
Rehabilitation Engineering Internship (6)
Special Problems - Rehabilitation Engineering (3)
Artificial Intelligence and Expert Systems (3)
Human Factors in Engineering Systems (3)
Electives (6)

Applicants are recruited nationally and are required to have an undergraduate degree in an appropriate engineering field. Stipends, tuition and fees, and travel expenses for field trips to rehabilitation facilities and conferences are provided under the training grant.

Three-day Seminars for Rehabilitation Practitioners (Counselors and Supervisors)

This training was developed to assist rehabilitation counselors and supervisors in meeting their clients' need for rehabilitation technology. To accomplish this, intensive training programs will be conducted at the Center. The training will include the following elements:

* using technology as a tool in rehabilitation
* funding for assistive devices
* review state-of-the-art in adaptive equipment
* case studies of clients utilizing assistive devices

In this curriculum, the participants will have didactic, practical, and "hands-on" experiences in the Center's assessment laboratories.

Two-day Seminars for Rehabilitation Educators

This training provides rehabilitation educators with an overview of rehabilitation technology as well as experience in various assessment laboratories and hands-on experience with a number of assistive devices. The training will include the following elements:

* overview of assistive technology in rehabilitation practice
* developing instructional course material
* review of proposed syllabus and selected readings

One discussion topic will be: "strategies for locating technology-based resources in one's local area." Participants will be encouraged to utilize this knowledge through networking with other professionals in the state and region.

Advanced Training for Adaptive Driving Personnel

A one-week training program will be provided for driver evaluators and educators from facilities that are currently providing driving assessment services. The training will include the following elements:

* hands-on experience in both clinical and in-vehicle settings
* participation in two driving assessments
* on-road performance testing
* interpretation of test results
* adaptive device/vehicle modification recommendations
* report writing and documentation

Participants will receive a resource manual and will be able to see the latest equipment in adaptive driving controls.

Clinical Training in Augmentative Communication

A two-week training program will be provided for speech/language pathologists and occupational therapists who are currently providing augmentative communication (AC) assessment services. The training will include the following elements:

* an overview of AC devices
* seating and positioning and its influence on communication
* hands-on experience with adaptive switches and communication devices
* access and use of microcomputers
* assessment and implementation for AC devices

Advanced Training for Practitioners in Rehabilitation Technology Services

The need for training of non-engineer rehabilitation technologists will be addressed by means of a highly specialized two-week training agenda which includes substantial time in clinical laboratory activities. Client assessment experience will be integrated into this competency-based training curriculum. Center assessment laboratories have two-way mirrors to permit trainees to observe details of assessment procedures prior to their being personally involved in this type of activity. Competency-based instruction units will be developed for the following:

* aids for independent living
* seating and positioning
* augmentative communication
* wheelchair prescription (manual and powered)
* job analysis techniques and job site modification procedures
* adaptive driving assessment and education

Paul N. Hale Jr., Ph.D., P.E.
Louisiana Tech University
P. O. Box 3185
Ruston, LA 71270

19.2

A Training Program for Ambulatory Adults with Cerebral Palsy that Improves Lifting Capacity

Monique CS Lanciault
Boeing Commercial Airplane Co. Wichita Division
Wichita, Kansas

ABSTRACT

Seven ambulatory adults (5 males and 2 females) with cerebral palsy (CP) participated in a training program designed to increase physical work capacity (PWC) and lifting capacity. An eight week training program was performed on a Schwinn Air-Dyne Ergometer (SAE) twice a week for 30 minutes at an intensity of 60-80% of peak heart rate. Prior to and following training, PWC was determined by exercise tests on the SAE. Twenty simulated lifting tasks were performed before and after training. Following training, significant increases ($p<.05$) in peak PWC (relative and absolute) and heart rate were seen on the SAE. Prior to training, males worked within 33% of PWC in 13/20 lifting tasks and females worked within 33% of PWC in 14/20 lifting tasks. Following training, both genders demonstrated improvement in lifting capacity with males working within 33% of PWC in 20/20 lifting tasks and females in 15/20 lifting tasks. The latter results suggest that the training regimen could have improved lifting capacity through a "task hardening" process on the SAE.

INTRODUCTION

The role played by rehabilitation engineers to increase the number of adults with CP in the workforce involves matching physical limitations of individuals to the task. A specific task at the workplace is designed/redesigned to fit within a specific percentile (33%) of the adults PWC. Little research, however, has addressed the feasibility of increasing the number/kinds of possible work tasks or increasing the time spent at that task by improving the PWC of these individuals. Indeed, the research that was concerned with training programs for individuals with CP have primarily focused on children and adolescents (1-4).

The purpose of this study was to design a training program for ambulatory adults with CP that would not only improve their PWC, but also their job related working capacity simulated by lifting tasks.

METHODS

Subjects

Seven ambulatory adults with CP (5 males and 2 females between ages 18-65) were selected for participation in this study. All subjects were employed. Their descriptive characteristics are shown in Table 1. Prior to testing, subject's gave written consent for all procedures. This research was approved by the Institutional Review Board for human subjects.

Testing Protocols

Maximal testing to determine PWC was performed on the SAE. The SAE is an air-braked ergometer which utilizes the resistance of air on wind vanes set perpendicular to the fly wheel to provide workloads ranging from approximately 25 watts to 500 watts and a pedaling speed ranging from 29 to 72 rpms, respectively. The SAE involves both upper (push/pull) and lower (cycle) body musculature. The exercise test on the SAE consisted of exercising at an initial workload of approximately 25W (29rpms) for two minutes and increasing the workload approximately 25W (an average of 4 rpms) every two minutes until volitional exhaustion. The SAE has been shown to elicit higher physiological responses (i.e., heart rate, oxygen consumption, minute ventilation) for ambulatory adults with CP when compared to treadmill, bicycle ergometer, and arm crank ergometer (5) and was, therefore, chosen for evaluating PWC as well as the training mode in this study. The SAE test was performed before and after training to determine if changes in PWC had occurred.

All subjects performed 20 lifting tasks. The simulated lifting tasks included lifting from floor to table height (76.2 cm) in three directions: (1) within the same plane, (2) at right angles, and (3) within the same plane but at 180°. Lifting from table height to a height at the same level was also required in the following directions: (1) at right angles, and (2) within the same plane but at 180°. All lifts involved weights of 0.909 kg and 2.727 kg at frequencies of two (low) and six (high) lifts per minute. The simulated tasks were run both before and after the training program.

Training Regimen

The eight week training program consisted of exercising on the SAE. The SAE was located in the gym of the residential community where six of the subjects lived. There was also an SAE located in the laboratory where all testing was conducted. Subjects trained on the SAE at approximately 60-80% of their peak heart rate as determined from the exercise test on the SAE. Subjects exercised twice weekly for 8 weeks at a duration of 30 minutes each time. Each session included a 5 min. initial warm-up for the first two weeks which was then lowered to two minutes by the third week, and a two minute warm-down after each thirty minute session.

Physiologic Variables

Throughout pre- and post-training exercise testing and lifting tasks, subjects' expired air was monitored by a metabolic measuring cart (SensorMedics 4400) which determined oxygen consumption (VO2, mL/min) carbon dioxide production (VCO2, mL/min) and respiratory quotient, R, (VCO2/VO2). Heart rates were monitored continuously by telemetry (UNIQtm, HeartWatch) and recorded every 30 seconds. For the SAE exercise test, blood pressure was measured before exercise, during the last minute of each work level, and following the test until it returned to resting levels. For subjects who needed their arms for stability during this test, exercise was stopped

TABLE 1: SUBJECT CHARACTERISTICS MEANS AND (STANDARD DEVIATIONS)

	Males (N=5)		Females (N=2)	
Age (years)	29.60	(2.87)	33.00	(10.00)
Weight (Kg)	77.27	(12.87)	60.91	(9.32)
Height (cm)	170.43	(2.69)	152.07	(3.48)

following each workload and blood pressure was promptly measured. Blood pressures were not measured during lifting tasks. An electrocardiogram (leads I, II, III, AVR, AVL, AVF, V1, V2, V5, and V6) was monitored throughout the pre-training test to detect dysrhythmias.

Statistical Analysis

Means (x) and standard deviations (SD) were calculated for all variables. Pre- and Post-training peak absolute PWC (VO2 mL/kg-min), heart rate (HR, bpm), and R were compared using a paired Student t-test. The experimental design for physiological requirements of the simulated lifting tasks was a randomized complete block design.

RESULTS

Mean and standard deviations for peak absolute and relative PWC, HR, and R before and after training are presented in Table 2.

TABLE 2: MEANS AND (STANDARD DEVIATIONS) OF PWC PRE VS. POST TESTS

Mode of Exercise		SAE	
HR Peak (bpm)	pre	176.00	(19.00)
	post	183.00	(12.00)*
PWC (mL/min)	pre	1930.00	(657.00)
	post	2692.00	(651.00)*
PWC/BW	pre	26.80	(6.00)*
(mL/kg-min)	post	30.00	(6.00)
R	pre	1.09	(0.09)
	post	1.14	(0.08)

* = Significant ($p<.05$) increases

Results of a paired t-test revealed that there was a significant increase in peak absolute and relative PWC and peak HR following training. Before training, males worked within 33% of PWC in 13/20 lifting tasks and females in 14/20. Following training males worked within 33% of their PWC in 20/20 lifting tasks while females showed a significant decrease ($p<.05$) between pre- and post-training %PWC for lifting tasks when genders were combined.

DISCUSSION

For safety purposes, guidelines have established a physical limitation for any work tasks of 33% of PWC for an eight hour work day (6). Results from the pre-training lifting tests indicate that for males and females 35% and 30% of the lifting tasks were above the physical limits for an eight hour work day. Findings following training demonstrate that these individuals significantly decreased the number of tasks they worked that were above 33% of their PWC. The study results mark a strong relationship between PWC and work related task capacities for this population. Also, the results of this study strongly suggest to vocational rehabilitation organizations another means of expanding job opportunities for ambulatory individuals with CP besides design/redesign of specific tasks to fit within the physical limitations of these individuals. Improving PWC is a major factor in improving job options available to this group.

CONCLUSION

The seven subjects in this study showed improvements in their PWC as a result of the training program. On average, PWC increased during the simulated lifting tasks, and the number of tasks which the subjects had to work at or above 33% of their PWC decreased significantly after training.

Acknowledgements

This research was funded by a Cerebral Palsy Research Foundation of Kansas grant through Dr. J. Fernandez of Wichita State University. I wish to thank K. Campbell, M. Klein, and T. Fredericks for their help. Special thanks to Dr. K. Pitetti for all his contributions.

REFERENCES

1. Berg,K., Effect of physical training of school children with cerebral palsy. Acta Paediatr. Scand. Suppl., 1970, Vol. 204, pp. 27-33.
2. Berg, K. and Bjure, J., Methods for evaluation of the physical working capacity of school children with cerebral palsy, 1970.
3. Lundberg, A., Changes in the working pulse during the school year in adolescents with cerebral palsy. Scandanavian Journal of Rehabilitation Medicine, 1973, Vol. 5, pp. 12-17.
4. Bar-Or, O.; Inbar, O.; and Spira, R., Physiological effects of sports rehabilitation program on cerebral palsied and post-poliomyelitic adolescents. Medicine and Science in Sports, 1976, Vol. 8 pp. 157-161.
5. Pitetti, K.H., J.E. Fernandez, M.T. Betzen, and M. Lanciault. Peak cardiopulmonary responses of ambulatory cerebral palsy adults to four types of exercise modalities. RESNA, Association for the advancement of Rehabilitation Technology. Proceedings of the 13th Annual Conference on Rehabilitation Technology, RESNA press, Washington, DC, 1990, pp. 55-56.
6. NIOSH, Work Practice Guide for Manual Lifting. NIOSH Technical Report No. 81-122. National Institute of Occupational Safety and Health, Cincinnati, Oh., March, 1981.

Monique CS Lanciault
Boeing Commercial Airplane Co. Wichita Div.
P. O. Box 7730 -- Mail Stop K25-81
Wichita, KS 67277-7730

19.3

A COMPUTER-CONTROLLED, WHEELCHAIR-GUIDED BOAT FOR THERAPY AND RECREATION

Michael Burrow, Cabell Heyward and Riley Hawkins
Georgia Institute of Technology
Center for Rehabilitation Technology
Atlanta, Georgia USA

Abstract

A wheelchair controllable boat has been developed to fulfill two primary missions: to serve as an introduction to water sports for the disabled, who either because of the envisioned safety risk, or because of the unavailability of accessible boating, have never been on the water, and also to provide a completely independently operated recreation opportunity for the experienced boater. Completed in late summer 1990, it is the first known boat designed specifically for persons in wheelchairs. It is powered by two 3 HP electric motors, and is controlled in the same manner as a wheelchair. An on-board computer automates the wheelchair tie-downs and docking, and regulates the speed of the motors. It can be boarded, piloted and docked completely independently.

Background

This project began in June of 1989 in response to recreation therapy needs at the Roosevelt Warm Springs Institute for Rehabilitation and also in response to the large number of disabled individuals who are not exposed to the benefits of boating because of safety concerns or the lack of an accessible boat. The purpose of this project was to address these issues.

A new method of restraint for wheelchairs was developed, and new methods of piloting a boat and docking were developed to minimize safety risks, so that it would be possible for the boat to be used recreationally without the need for assistance.

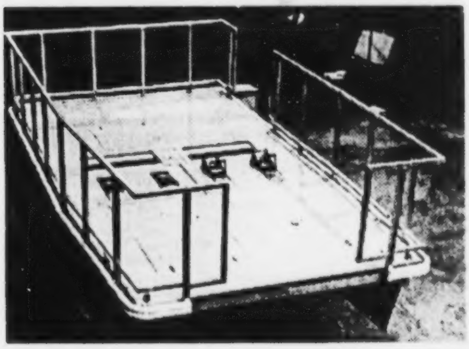


Figure 1. Photograph of the Wheelchair Controllable Boat.

Design and Development

The wheelchair controllable boat is supported by two 22" foam filled pontoons, approximately 13 feet, 6 inches in length and spaced 6 feet, 8 inches apart. The pontoons are rigidly held by a frame of 3/8 inch thick aluminum beams which support the deck of pressure treated studs and 3/4 inch marine plywood. A thirty inch railing surrounds the 8 by 14 foot deck with an entrance on the port side, aft, and an exit at the bow. The deck is flat except for the four tie-down mechanisms which are equally spaced across the width, equidistant between the bow and stern. These tie-downs and other mechanical and electrical components can be accessed for servicing through hatch doors located in the deck.

Access hatches to a storage compartment and the compartment housing the on-board computer are located near the bow. The computer consists of a BCC52 microcontroller which operates the tie-down mechanisms, trolling motors, and other functions of the boat. The wheelchair controllable boat is shown in figure 1.

A block diagram of the control scheme is shown in figure 2. The microcontroller contains an 8052 microprocessor, RAM and EPROM, and an RS232 link to a host computer used for programming and debugging.

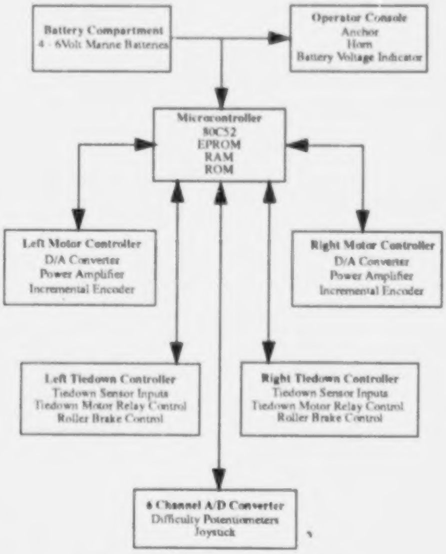

Battery Compartment
4 - 6Volt Marine Batteries
Operator Console
Anchor
Horn
Battery Voltage Indicator
Microcontroller
80C52
EPROM
RAM
ROM
Left Motor Controller
D/A Converter
Power Amplifier
Incremental Encoder
Right Motor Controller
D/A Converter
Power Amplifier
Incremental Encoder
Left Tiedown Controller
Tiedown Sensor Inputs
Tiedown Motor Relay Control
Roller Brake Control
Right Tiedown Controller
Tiedown Sensor Inputs
Tiedown Motor Relay Control
Roller Brake Control
6 Channel A/D Converter
Difficulty Potentiometers
Joystick

Figure 2. Pontoon Boat Control Scheme.

Once the software was written and tested, the code was stored in EPROM and the host computer removed. A bus structure is used to communicate with the peripheral cards which monitor and control individual components of the boat. One peripheral is responsible for monitoring the tiedown mechanisms. When a wheel has been detected in the tiedown, the controller instructs the mechanism to close on the wheel. It will also determine whether one or two persons are using the boat based on which

BEST COPY AVAILABLE

pair of tiedown mechanisms have been activated. Behind these are access hatches for the motors which power the tie-down mechanisms. These tie-downs were developed specifically to hold only the front casters of a wheelchair to allow the rear wheels to spin freely.

The clamping action is started as the caster wheels roll onto a series of parallel spring steel fingers, aligned along the length of the boat and arching above the deck by 1 1/2 inches. As they are depressed by the wheelchair rolling over them, the caster is held from rotation and the tie-down motor is switched on. If the two starboard tie-downs are activated, the wheelchair will be locked into place and the system will wait for a wheelchair to engage the port side before activating the trolling motors (and vice-versa). A detailed diagram of the tie-down mechanism is shown in figure 3.

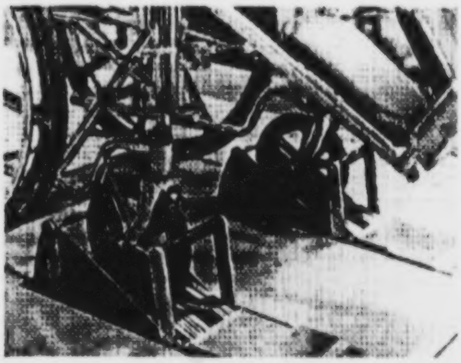


Figure 3. Tie-Down Mechanism with Casters in Position.

As the tie-down motors are activated, two clamping bars, located at each end of and perpendicular to the spring steel fingers, are brought up from the deck and inwards toward the caster wheel until the proper clamping pressure is reached. Two 8 1/2 inch diameter rollers are located behind the four tie-downs. These are in-line across the width of the boat and protrude 1/4 inch above the deck. As the front casters wheels are clamped, the rear wheelchair wheels are brought to rest directly on top of the rollers. A brake will hold the rollers in place as the wheelchair maneuvers into tiedown position. Once in place, the roller brake is released allowing the rear wheels to roll freely.

Another peripheral is responsible for monitoring the rollers and controlling the speed and direction of the motors. An incremental encoder mounted inside each roller provides positioning information to the controller. A HCTL-2020 quadrature decoder and 16-bit counter is used to track movement of the incremental encoder. The position of the roller is read repeatedly and the difference between the last position and the current position is determined. Since the time required to perform the read and the time between the reads is known, the velocity and direction of the roller can be calculated. This information is then scaled and represented by a 7-bit number. This number represents the magnitude of the velocity of the roller. The eighth bit or sign is used to determine the direction of the roller. The 7-bit number plus sign is routed to a digital-to-analog converter which provides an analog signal proportional to the speed and direction of the respective motor.

In this way, a wheelchair can be clamped rigidly into position and the operator can control the boat through motion imparted to the rear wheels. This configuration of two rollers and four evenly spaced tie-downs allows either two wheelchairs to pilot the boat, one controlling the starboard motor, and the other, the port; or one chair to control both motors by using the two center tie-downs, and thereby running the starboard motor with his right hand wheel, and the port motor with his left. In this way, it is no more complicated to control the boat than it is to control the wheelchair.

Directly behind the rollers is the access hatch to the tub containing four 12 volt deep cycle marine batteries which power the trolling motors, all control motors, the computer, running lights, etc. for 9 hours of continuous use. The batteries are recharged daily by plugging into a recharger located at the dock.

Docking will be made easier by the use of underwater guides which help to funnel the boat in place as it approaches the dock. Also, there is a bar protruding from the dock which mates with a solenoid operated latch centered on the bow of the boat to ensure that the deck meets the dock accurately enough for wheelchairs to disembark.

Since safety is of primary concern, the boat has a very stable hull and is used only in the sheltered waters of a 15 acre lake. Power by electric motors insures that physical exhaustion doesn't pose the safety risk of leaving one stranded without the strength to get back to the dock. The tie-down system proves effective as it releases the boat from the dock once it is engaged and doesn't disengage (unless the operator overrides) until the boat is completely docked.

A difficulty adjustment has also been incorporated into the boat so individuals with varying strengths can control the boat. If the difficulty switch is at its lowest setting, slight movements of the rear wheels on the chair will cause the boat's motors to drive at full speed. Conversely, if the difficulty switch is at its highest setting, the wheelchair must the driven rapidly to make the motors on the boat drive at full speed.

The strength advantage of one user over the other can be compensated. The advantage of each person operating the boat simultaneously can be compensated so that more cooperative piloting will be possible.

Evaluation

The boat will be evaluated at the Roosevelt Warm Springs Institute for Rehabilitation on a private lake owned by the Institute. At the time of this writing, it is planned to launch the boat in the spring of 1991 and begin evaluation immediately. Patients will be asked to evaluate the boat's effectiveness and ease of use.

Discussion

The project is ongoing and improvements are made as funds are available. Future plans include automation of controls which now require mouthstick use or can only be operated by paraplegics and a remote control system by which a life guard or supervising therapist, at the dock, can override the controls on the boat and steer it back to the dock should it become necessary for safety reasons. Also, there is the possibility of radio communication between the boat and the dock, and monitoring the vital signs of the operators from the dock.

Acknowledgments

Funding for this project was provided by the Center for Rehabilitation Technology and the State of Georgia Division of Rehabilitation Services.

Michael Burrow
Center for Rehabilitation Technology
Georgia Institute of Technology
400 Tenth Street
Atlanta, GA 30332

Foot Operated Hold Down

Ray Rego
Rehabilitation Technology Center
Indianapolis, Indiana

Introduction

Many people with one hand or with only the functional use of one hand, must do job tasks that require two hands. This device uses foot power to hold down work as if it were a second hand. It is a simple, strong and easy to use device. It is also fitted with a table to allow extra work space.

Method

The Hold Down is constructed of steel for strength, rigidity and cost effectiveness. It is constructed of seven main components, a base, a mast, a foot plate, a hold down arm, a connecting link, a clamping table and a counter weight.

The base is heavy steel for stability.

The mast is 2 inch square tube.

The foot pedal is made from flat steel weldments and has a series of holes for positioning attachment to the mast, connecting line and counter weight.

The hold down arm is similarly constructed of flat steel weldments with a series of holes for attachment to the mast, connecting link and adjustments. It has rubber hold down fingers for grip.

The tubular connecting link attaches to the foot plate and hold down arm by threaded adjustable links. The placement and adjustment of the connecting link change the stroke and the amount of pressure to use the device.

The steel table attached to the mast is approximately 6 x 10 inches and gives a firm clamping base.

The counter weight is a sealed box with a threaded fill hole which allows sand to be used as a variable weight agent. This counter weight makes the device work effortlessly and also return the hold down arm to its neutral position without the use of springs.

The extra component is a laminate topped table that gives an extended work surface. This table rests directly on the steel clamping table and allows for a great amount of pressure to be exerted without bowing or buckling the work surface.

By adjusting the components, clamping of various thicknesses and materials can easily be accommodated. The length of strokes and foot pedal height are also easy to adjust.

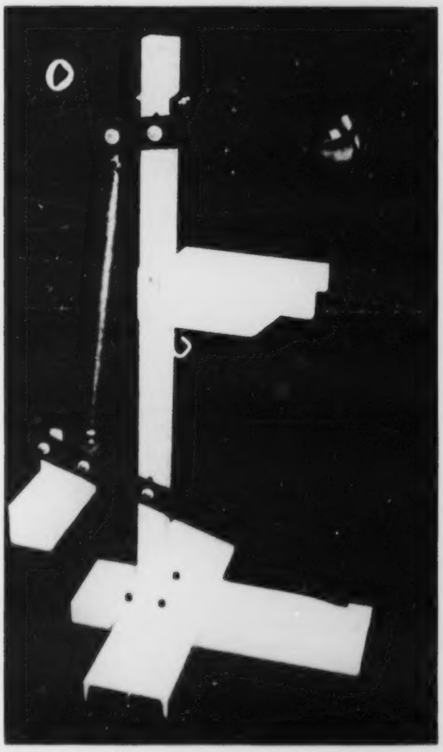
Conclusion

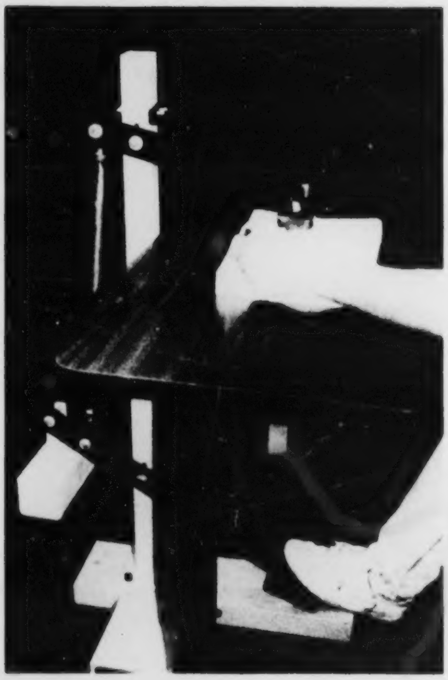
This device allows for the easy holding down of various materials with foot pressure. It will allow a one handed person to do several two handed functions.

Acknowledgment

This work was supported by the Indiana Department of Human Services.

Ray Rego
Rehabilitation Technology Center
6862 Hillsdale Court
Indianapolis, Indiana 46250





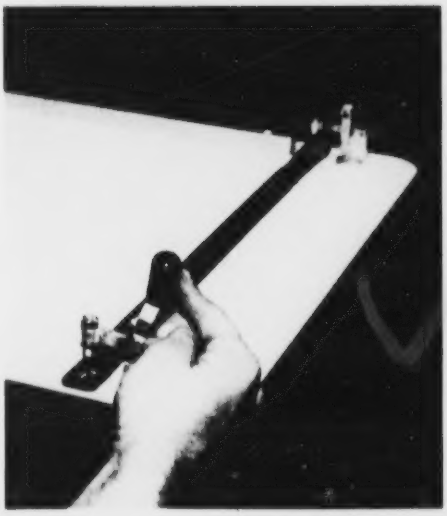
BEST COPY AVAILABLE

One Handed Paper Folder

Ray Rego
Rehabilitation Technology Center
Indianapolis, Indiana

Introduction

Working with several clients with the functional use of one hand, the problem of folding paper has been a reoccurring one. Holding the paper, creasing and folding it, is difficult at best. This problem was the basis for developing this product.



Method

This device is composed of three elements, a stable base, an alignment bar and a locking folding/creasing bar.

The base is made of 3/4 inch plywood with a non-skid rubber bottom and formica top. This allows for stability in using this device along with a serviceable surface. An aluminum bar is attached to the top surface of the base parallel to one edge so that a piece of paper can be slid along it to square the paper to the fold.

The paper is then slid under the stainless steel folding bar and is locked in place. This bar is constructed of stainless steel and has a thin foam layer on its bottom side for better gripping of materials.

Paper held square and straight is easy to crease and fold. The size of the device allows for many sizes of foldable material and the adjustments of the folding bar allow for various thicknesses and types of material.

Conclusion

This is a simple device that can be very effective in aiding clients with a very frustrating problem. It can be modified to deal with the special needs of a client at modest costs.

Acknowledgment

This work was supported by the Indiana Department of Human Services.

Ray Rego
Rehabilitation Technology Center
6862 Hillsdale Court
Indianapolis, Indiana 46250

Technology and Employment

Diane C. Bristow, M.S.
Office of Disabled Student Services
California State University, Northridge

Abstract

Employment opportunities are available for many disabled individuals who were previously considered unemployable. The provision of appropriate assistive technology has made this a reality. The occurrence of this, however, still remains limited. This presentation will offer one method of increasing the knowledge of rehabilitation counselors, rehabilitation facilities personnel and employers on assistive technology. Case presentations through slide and videotapes will be shown to illustrate successful employment by the severely disabled.

Background

Individuals with severe motor and/or speech impairments have long been considered to have limited potential for employment. With the provision of appropriate technology, however, these individuals have a greater opportunity for successful employment. Despite the existence of the technology, few individuals with severe impairments are becoming gainfully employed or are maintaining their previous levels of employment. This may be due to a lack of knowledge of what is available, poor or nonexistent assessment procedures and/or unavailable funding. Modifications in our current system needs to be adopted to change this situation.

Objective

If our goal, as a society, is to increase the number of disabled individuals in the workplace, specific procedures need to be adopted. Of primary importance is education. Rehabilitation professionals, disabled individuals and employers need to be provided with ongoing training regarding available assistive technology and its application in the workplace. The second major objective should be the establishment and use of assessment teams to match the most appropriate technology to the individual. While assessment teams do exist, disabled individuals may either be unaware of them or may not be able to be seen by them due to financial or travel considerations. The final area is the need for better coordination and access of funding.

Approach

The first objective is currently being addressed by the Office of Disabled Student Services at California State University Northridge. Through a three-year renewable grant from the Department of Education's Rehabilitation Services Administration, training on assistive technology is being provided to rehabilitation counselors, rehabilitation facilities personnel and employers in Federal Region IX. Federal Region IX includes California, Arizona, Nevada, Hawaii, Guam, American Samoa and Saipan. The training program provides information on technology for the blind and visually impaired, deaf and hearing impaired, physically challenged, communication impaired and cognitively impaired. As part of the training, participants are provided with hands-on experience with assistive technology. In addition, workshops may focus on exploring possible assistive technology applications for specific jobs and disabilities. As part of the project, a videotape was developed which presents various individuals currently employed through the use of technology. Included in this tape are disabled individuals who are respirator dependent and augmentative communication users. Assistive technology has offered these persons the ability to be gainfully employed.

Results and Discussions

Through the training program, the targeted audiences have demonstrated an increase in their knowledge of available assistive technology. More importantly, participants have independently continued to explore technology applications within employment settings after the training sessions. The current implication is that more training opportunities are needed throughout the United States With increased knowledge of available assistive technology, the severely disabled have a greater opportunity to achieve employment success.

Acknowledgements

Funding for this grant was provided by the Department of Education, Rehabilitation Services Administration. Grant #H129R9007.

Diane Bristow, M.S.
RSA Trainer
Office of Disabled Student Services
California State University, Northridge
18111 Nordhoff Street - DVSS
Northridge, CA 91330

20.1

SPEECH RECOGNITION TO ENHANCE COMPUTER ACCESS FOR CHILDREN AND YOUNG ADULTS WHO ARE FUNCTIONALLY NONSPEAKING

J. Treviranus, F. Shein, S. Haataja, P. Parnes†, M. Milner†
The Hugh MacMillan Rehabilitation Centre
†and the University of Toronto
Toronto, Ontario

ABSTRACT

Many children and young adults who are severely physically disabled and functionally non-speaking use scanning techniques to control computers. This study investigated whether combining speech recognition with scanning can increase the rate of computer input for these individuals. The study compared two access techniques: traditional scanning and scanning combined with speech recognition. Six participants were involved in this study. The results of one participant are presented here in the form of a case study.

BACKGROUND

Although children with severe physical disabilities may use alternative computer access systems (e.g., scanning, morse code), these are often slow and restrictive (Vanderheiden and Kelso, 1987). These children are therefore greatly handicapped in their attempts to keep up with peers in integrated educational settings. Strategies to accelerate access methods (e.g., abbreviation-expansion, prediction) have made relatively minor gains at the expense of additional cognitive processing demands (Light, 1989). Tapping a larger proportion of the child's controllable actions through a "hybrid" access method has not yet been investigated.

Instead of trying to accelerate input using a single access technique, it may be more effective to combine different methods into hybrid techniques (Shein, Brownlow, Treviranus, Parnes, 1990). Many nonspeaking children who converse by selecting items from non-technical communication displays use a combination of scanning and direct pointing. Although their pointing skills are insufficient to pick out individual items, these children can use eyegaze or gross pointing to indicate groups of items. Listeners can then call out or point to items in a group until the child signals that the desired item has been reached. Since the child directly points for speedy access to groups of items, and need only scan within a group, less scanning is required to select an item.

Although they may not have sufficient physical control even for gross pointing, many children who are nonspeaking are able to vocalize. The average listener may not identify these vocalizations as words, but the utterances may be distinguishable from one another. It may be possible, therefore, to supplement the scanning systems which these children generally use with a speech recognition system which maps words or word approximations into computer input. Distinguishable utterances could serve as direct selectors, performing the pointing function which these children cannot physically accomplish. In a hybrid system, children could either scan through or directly select groups of items, followed by items within the groups.

Some commercially-available speech recognition systems do not require intelligible words; they simply match a voice pattern with one previously recorded. Fried-Oken (1985), Schmitt and Tobias (1986), and Rodman et al. (1984) report the successful use of such speech recognition systems with dysarthric speakers to write, to control the environment, and to clarify speech.

Our clinical observations of the use of speech recognition with several nonspeaking children and adults who are able to make a number of distinct utterances have noted a recognition accuracy of 70 to 88 percent with a vocabulary of 12 to 20 utterances. Although speech recognition would not be feasible as the sole input method for these individuals, it could accompany other input methods as part of a hybrid selection technique.

An important consideration in employing multiple input modes, especially with children, is cognitive processing. Forren and Mitchell (1986) found that combining speech recognition with keyboard entry slowed down able-bodied typists. They postulated that this was due to increased demands on the user's attention and processing resources. The user was required to devote cognitive resources to speaking each word in isolation, which is an unnatural method of speech, as well as attending to visual feedback in order to confirm entries.

For users of scanning systems, directly selecting by vocalization rather than passively waiting for the computer to present choices may in fact reduce the perceived cognitive load. Forren and Mitchell's conclusions may not apply to these users, since they are accustomed to dividing their visual attention between the text they are editing and the feedback from their scanning systems. In a hybrid access system, voice recognition feedback could be incorporated into scanning feedback in order to minimize any additional cognitive processing demands.

Theoretically, combining speech recognition with scanning could provide a faster, more direct means of computer access for people who use scanning. It is important to investigate the actual effect on rate, accuracy, and cognitive load for nonspeaking individuals.

RESEARCH QUESTIONS

The following hypothesis was proposed:

Combining speech recognition with scanning will increase the computer input rate for children and young adults who are severely physically disabled and functionally nonspeaking and who use scanning as a means of controlling computers.

The following specific questions were addressed:

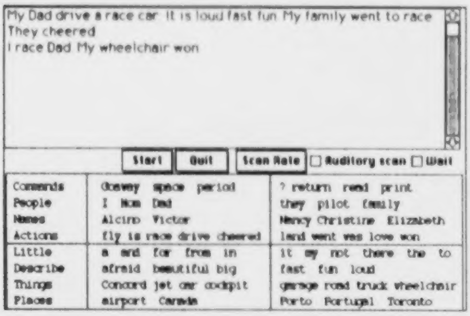
1) To what degree will the addition of speech recognition affect input rate and accuracy?
2) How do physically disabled, nonspeaking children and young adults rank the ease of using scanning alone, and speech combined with scanning? Which input method do they prefer?
3) How do speech intelligibility, severity and type of dysarthria, and consistency and distinctness of utterances affect input rate and accuracy across the different access techniques?
4) What is the rate of improvement across the series of learning sessions?

METHODOLOGY

Research Design

The research team addressed the above questions by studying two conditions, each employing a different access technique. For each participant, both conditions used the same visual matrix, vocabulary, and feedback (Figure 1). Individual matrices were designed for each participant based on their personal writing system in consultation with an augmentative communication consultant and the participant's clinical team. Participants and their clinical teams chose vocabulary items they deemed necessary or desirable for written communication.

The chosen words, phrases or letters were placed into logical categories using classifiers with which the participant was familiar. Classifiers or group headings appeared in the left-hand column of the matrix; words corresponding to group headings filled the rest of each row. Since the system was dependent upon grouping the vocabulary in meaningful classifiers, the participant's ability to use classifiers was



My Dad drive a race car It is loud fast fun My family went to race
They cheered
I race Dad My wheelchair won

Commands	Goaway space period	? return read print
People	I Mom Dad	they pilot family
Names	Alcino Victor	Nancy Christine Elizabeth
Actions	fly is race drive cheered	land went was love won
Little	a and for from in	it my not there the to
Describe	afraid beautiful big	fast fun loud
Things	Concord jet car cockpit	garage road truck wheelchair
Places	airport Canada	Porto Portugal Toronto

Figure 1: Sample page of a visual matrix employed for one participant.

assessed and taken into account. Participants had access to additional vocabulary by selecting page headings displayed in the top row. Selected words were sent to a text window above the matrix. The two conditions were as follows:

A) *Scanning*

The particiapnt selects from the matrix using their present mode of scanning and personal switch.

B) *Scanning combined with speech recognition*

Utterances were used both to replace the switches the participant used in condition A), and to directly select a row within a scanning matrix or a specific item. In this condition the participant selected the page, group or item by speaking an associated utterance or word approximation. If there was no distinguishable utterance for the desired page, group, or item the participant used a predetermined utterance to command the system to scan the rows or items and used another predetermined utterance to indicate that the desired item has been reached. To choose any item the participant first chose the group it belonged to and then the item. This reduced possible confusions among words recognized by the speech recognition system. The participant could use either scanning or voice at any stage in the selection procedure.

The study employed a within-subject counterbalanced design with repeated measures. All subjects participated in both conditions and the order of presentation of the two conditions were counterbalanced across participants to control for order effects. The counterbalanced design was chosen because of the heterogeneity and size of the subject group and to reduce the time commitment required of the participants.

The dependent variables studied included:

1) the net rate of input measured in correct entries per minute (a summary measure of rate and accuracy).
2) post hoc analyses of input errors,
3) ease of use rating by the participants, and
4) personal preference rating by the participants.

Participants
Six participants were chosen from the caseload of a local augmentative communication service. The ages of the subjects ranged from 5 years to 21 years of age. Several were only beginning to establish literacy.

Participants met the following criteria:

1) their means of written communication employed traditional orthography as the representational set,
2) their means of computer input was scanning with discrete switches,
3) their speech was inadequate to meet their daily communication needs, and
4) they could make three or more repeatable, but not necessarily intelligible, utterances which can be distinguished by a speech recognition system.

Procedures
Participants took part in one introductory session followed by eight learning sessions for both conditions. A "probe" test was included in each learning session to test for rate and accuracy of input. During the learning session each participant engaged in motivating, age appropriate tasks which maintained their attention and which required a minimum of skills not associated with controlling the access technique.

Three sets of equivalent tasks were created prior to the study and randomly assigned to each of the three conditions. At the end of each learning session the participant performed a short copy typing task. The researcher recorded the gross rate of input in items per minute. Text produced was scored to determine the net rate of input (number of correct items entered per minute). Errors and corrected errors were also recorded. In order to minimize interference effects, the conditions were separated by at least one week during which no training was provided.

An assessment of the participants' oral motor function, phonation, and general intelligibility of speech was performed by a qualified speech language pathologist using standardized measures or standardized measures appropriately modified to accommodate the severe dysarthrias of the participant group. Each participant was also tested for the number of utterances recognized by the speech recognition system from a predetermined list of 30 words.

Equipment
The scanning interface was developed on the Macintosh™ SE/30 computer using HyperCard.™ Speech recognition was performed by the Voice Navigator™ recognition unit, a device specifically designed for the Macintosh.

RESULTS

As this research is in progress this discussion will be confined to the performance of the first participant. Of the 6 participants taking part in this study this participant has the fewest discrete, repeatable vocalizations (3 versus 58 by participant 2). Whereas the remaining participants used vocalizations to directly select rows and items, this participant used the vocalizations to choose functions which enhanced his scanning.

Case Study
L.B. was a 12 year-old-boy with cerebral palsy (spastic quadriplegia). He was attending a segregated school. His reading and spelling level were both estimated to be at grade 1 to 2. He was using a MOD Keyboard access system to write at school (Lee, Shein, Parnes, & Milner, 1985). When screened with this system he was writing at a rate of 2.3 selections per minute. He controlled the scanning system using two head switches. One switch was used to select row and item while the other switch was used to escape from an unwanted row.

L.B. used a multiple page communication folder with Blissymbols and words to communicate face-to- face. The vocabulary items in his folder were organized using a modified Fitzgerald key (i.e., subject, verb, adverb, adjective, object, place, time words, alphabet and numbers). Familiar listeners reported that L.B. rarely used vocalizations to communicate. L.B. did not use vocalizations to gain attention, acknowledge or deny.

During the screening L.B. was not able to repeat or read any words intelligibly. When screened using the voice recognition system L.B. was able to produce three discrete, repeatable utterances: "ma" for mom, "hey" for hello, and "heya" for table. No other vocalizations could be added without confusions (e.g., "heyma") .

L.B. chose to write about concord jets, remote cars and trucks, and a pet rat during his learning sessions. As the participant was developing spelling skills, whole words were used as vocabulary items. The probes were created by a professional who was blind to the exact order of the vocabulary in the matrix, and was randomly selected following the learning session. In condition B one vocalization was used to delete the last selection, a second vocalization was used to skip to the second half of the rows or the second half of the columns, a third vocalization was used to select the row of verbs.

As can be seen from Figure 2, L.B. performed better using scanning and vocalizations from the first probe onward. There were no uncorrected errors. In 56% of the errors an adjacent row or item was selected, in 23% of the errors an incorrect row was selected. The subject made an average of 3.6 errors in the scanning condition and an average of 3.9 errors in the scanning combined with speech recognition condition. Vocalizations needed to be repeated an average of 1.6 times prior to recognition. Voice training remained recognizable from session to session unless the environment was drastically changed (e.g., from classroom to small room with noisy overhead fan).

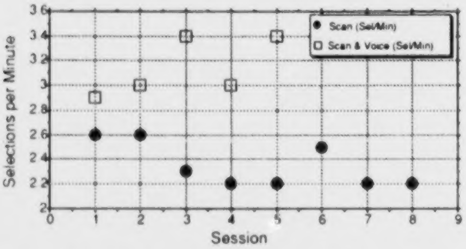


Figure 2: Selections per minute for participant L.B.

Environmental white noise (e.g., overhead fan or heating system) seemed to effect the performance of the speech recognition system far more than other environmental noises (e.g., voices of classmates, banging, etc.). The speech recognition system was also very sensitive to the position of the microphone. Internal straps from a construction helmet were used to mount the microphone rather than the head mount which came with the system.

DISCUSSION

Both participants studied to-date performed better in selections per minute when using the scanning combined with speech recognition condition. The statistical significance of these findings are yet to be determined. As these results were evident from the first sessions onwards it appears that the additional learning demands of using two selection techniques were outweighed by the gains in efficiency. Judging from text created during the learning sessions (during which participants composed their own text rather than copy typing text), any additional cognitive demands did not seem to interfere with the task of writing.

Given the results so far it appears that gains in selections per minute can be made using scanning combined with speech recognition even with a very limited set of discrete vocalizations. Results from the remaining participants should demonstrate the effects that the number of discrete vocalizations have on gains in performance. Performance results from the remaining participants are required before any conclusions can be reached concerning the general application of these findings.

ACKNOWLEDGMENTS

We thank the Easter Seal Research Institute and the Hospital for Sick Children Foundation for their support. Apple Canada Ltd. is also thanked for their generous loan of computer equipment.

REFERENCES

Fried-Oken, M. (1985) Voice recognition device as a computer interface for motor and speech impaired people. *Archives of Physical Medicine and Rehabilitation*, 66(10), 678-681.

Isaac, S. & Michael, W.B. (1978) *Handbook in Research and Evaluation*. San Diego, CA: EdITS Publishers.

Lee, K., Shein, F., Parnes, P., & Milner, M. (1985). The Elementary MOD Keyboard. *Proceedings of the Computer Technology for the Handicapped Conference*, Minneapolis, MN, 98–103.

Light., J.C. (1989) *Message encoding techniques for augmentative communication systems: An investigation of the recall performance of nonspeaking physically disabled adults*. Ph.D. Thesis, Department of Education, University of Toronto, Toronto, ON.

Rodman, R.D., Moody, T.S. & Price, J.A. (1985) Speech recognizer performance with dysarthric speakers: a comparison of two training procedures. *Official Proceedings of SpeechTech '85*, New York, NY, 22-24.

Schmitt, D.G., & Tobias, J. (1986) Enhanced communication for a severely disabled dysarthric individual using voice recognition and speech synthesis. *Proceedings of the Ninth Annual Conference on Rehabilitation Technology*, Minneapolis, MN, 23-26.

Shein, F., Brownlow, N., Treviranus, J. & Parnes, P. (1990) Climbing out of the rut: The future of interface technology. *Proceedings of the Visions Conference*, University of Delaware, Wilmington, DE.

Vanderheiden, G. & Kelso, D. (1987) Comparative analysis of fixed vocabulary communication acceleration techniques. *Augmentative and Alternative Communication*, 3(4), 196-206.

Macintosh and **HyperCard** are registered trademarks of Apple Computer, Inc.

Voice Navigator is a trademark of Articulate Systems, Inc.

ADDRESS

Jutta Treviranus
Microcomputer Applications Programme
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario M4G 1R8

EMOTIONAL SYNTHETIC SPEECH IN AN INTEGRATED COMMUNICATION PROSTHESIS

Iain R. Murray, John L. Arnott, Norman Alm & Alan F. Newell
Microcomputer Centre, Dept. of Mathematics and Computer Science,
University of Dundee, Scotland, UK.

ABSTRACT

Development of a rule-based system to add vocal emotion effects to synthetic speech using a commercial synthesiser is described. The output from the prototype system was evaluated positively by naïve listeners, and the system has been incorporated into an integrated communication prosthesis for the disabled.

BACKGROUND

Many communication prostheses use synthetic speech devices for output. It has not previously been possible, however, to include vocal emotion effects within such speech. The system described here was designed for integration into a predictive prosthesis (1), and has been combined with the PAL and CHAT prediction systems (2 and 3) to form a system which can produce a predicted phrase from storage or a unique phrase built up from predicted words, and speak it with emotive affect through a commercial speech synthesiser.

STATEMENT OF THE PROBLEM

Emotion is a very important constituent of human speech, often containing more information about the speaker and the message than the words themselves. It is thus highly desirable to include emotion capability in a communication device to allow disabled users to express themselves in a natural way. While earlier systems such as CHAT have had a "mood" capability, this has been achieved by the choice of word or phrase, and the actual voice of the synthesiser has remained neutral.

RATIONALE

Some isolated studies over the past fifty years or so have investigated which features of the voice alter when the speaker is expressing a particular emotion (see (4) for bibliography). This work indicated that emotion is carried by variations in three factors within the speech:

(i) voice quality,

(ii) pitch contour of the utterance, and

(iii) timing of the utterance.

The current project sought to alter these three factors within synthetic speech in a controlled way so as to simulate appropriate effects in order to suggest emotion in the voice. This was implemented by developing a set of voice control rules, allowing the effects to be implemented on any text entered into the system.

DESIGN

The HAMLET system (Helpful Automatic Machine for Language and Emotional Talk) was designed to operate on an IBM PC or compatible computer, and the prototype used the high quality DECtalk V2.0 synthesiser. The DECtalk offered a high degree of user control over the voice quality and phoneme parameters, as well as a voice with high intelligibility (adding emotion effect to a low quality synthesiser might result only in further loss of intelligibility). The prototype version of HAMLET was conceived as a stand-alone system for developing and testing the emotion rulebase. It allows an unrestricted text phrase to be entered, converts this into phoneme representation (using the DECtalk), and then allows the user to select an emotion to speak it with; the emotion assignment phase takes about a second for a ten word phrase. The user interface displays each stage of the process, and the user can directly alter voice or phoneme values using the built-in screen if required for testing purposes. The voice editor can be used to create and store a new voice "personality", and could be used to tailor the voice to suit a non-vocal user.

DEVELOPMENT

Once a substantial amount of information had been gathered from the literature on human vocal emotion, it was decided to simulate six discrete emotions with the prototype HAMLET system; anger, happiness, sadness, fear, disgust and grief were selected, as these were the emotions about which most data was available. A rulebase was then developed, based on this literature, which included appropriate voice quality changes for each emotion, and a series of rules for altering particular features of the timing and pitch contours. The original rules were improved by subjective evaluation of the synthetic voice output and readjustment of the rules.

The emotion assignment process is additive with respect to the neutral speech parameters. The voice quality changes are subtle, based on the current voice settings (large changes alter the "personality" of the voice), and the phoneme pitch and duration (which in combination form the pitch contour and overall timing of the utterance) alterations are also additive to retain the stress and accent information within the utterance. The emotion module would therefore form a logical additional module in a text-to-speech system (5).

EVALUATION

After an initial pilot experiment to test the experimental procedure, a formal listening experiment was conducted with 35 paid subjects (university students). The experimental method was based on human emotion experiments, and involved the subjects listening to a series of phrases, and commenting after each one on the emotion which they perceived in the voice. In the first part of the experiment this was by unrestricted keyboard input, and in the second, the subject was forced to pick (by mouse) one emotion adjective from a list of fifteen (including distractors) displayed on the screen. The test phrases were of two kinds; half had emotive texts and half were emotionally neutral. These phrases were each spoken with neutral voice and with an emotional voice (in the latter case, corresponding to the textual emotion if appropriate). This design allowed the results of each phrase with neutral voice to be subtracted from the result for the same phrase with emotive voice, to give the net effect of adding the vocal emotion effects; these difference values were then analysed using McNemar's test. This was done only for the quantitative results of the forced response test; the free response results were not formally analysed, being used instead to identify particular problem phrases.

Results

For neutral phrases, a significant improvement (at the 5% level) in vocal emotion recognition was noted for about one third of the test phrases, and for emotive phrases, a significant improvement (at the 5% level) was noted for about one half of the test phrases. Figure 1 shows the average numbers of subjects who changed their identification of emotion between the two utterances of the same phrase, for the neutral and emotive phrase texts (eg. for neutral phrases spoken with anger, four more subjects on average thought it angry when the vocal anger effects were present, and one subject less thought the emotion was something other than anger). This shows that the emotions are recognised to differing degrees. Disgust is the least convincing, and grief is the most realistic in context, but out of context it is more often perceived as sadness.

DISCUSSION

The results of the listening experiment suggested that the HAMLET system was producing recognisable vocal emotion effects. These were found to be larger for emotive texts than for neutral texts, and the recognition rate also fluctuated between emotions; this also occurs with human speech, and similar rankings were found to earlier studies (6). Work on HAMLET is continuing to develop and improve both the realism of the emotions produced, and the range of emotions available. This work is based on an accepted three dimensional emotion model, and is controlled by specifying the three co-ordinates, rather than a particular discrete emotion.

An Emotive Communication Prosthesis

For use in a communication prosthesis, the HAMLET rulebase has been incorporated into the CHAT system (3). CHAT automatically navigates the user through a simple conversation by predicting appropriate phrases from a set appropriate to each conversation stage. In addition, a unique phrase can be input if required; this process uses the resident PAL system which predicts words based on their frequency and recency of use (2). Combining HAMLET with the other systems required removal of the HAMLET screen handling procedures, and appropriate modifications to the CHAT user interface; careful earlier design of both systems facilitated this process. In conjunction with CHAT's existing mood capability using appropriate phrase sets, the HAMLET rules add a further dimension to the speech by adding vocal emotion effects. A method was devised for mapping the seven HAMLET emotions (including neutral) onto the four original CHAT moods (polite, informal, humorous and angry); Figure 2 shows the default mapping of the vocal emotions to the text moods. This system is now under evaluation; it may be that some combinations of phrase sets and vocal emotion are inappropriate, requiring addition of further phrase sets or simulation of different vocal emotions. It would be possible, however, to give more advanced

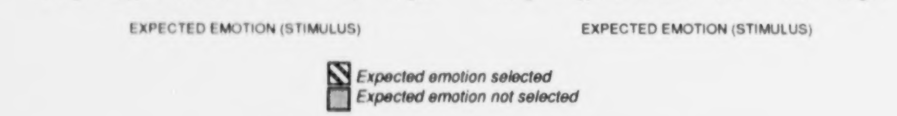


FIGURE 1: Average difference in vocal emotion recognition caused by addition of HAMLET vocal effects

CHAT users the capability to control their phrase moods and vocal emotions independently in order to generate further modes of expression (the empty cells in Figure 2), as has been demonstrated previously by some disabled CHAT users (eg. using anger phrases out of context with the neutral synthesiser voice in order to achieve humorous affect).

HAMLET VOCAL EMOTION

CHAT TEXT EMOTION	N	A	H	S	F	D	G
P	D			D	D	D	D
I			D				
H			D				
A		D					

FIGURE 2: CHAT / HAMLET EMOTION MAPPINGS
The default mappings are shown (D); the remaining squares represent possible further combinations which may be used for particular effects

CONCLUSION

A system for producing vocally emotive utterances has been demonstrated, and been found to produce emotions recognisable by naïve listeners. This system has been incorporated into a prototype communication prosthesis to allow the user to better express their feelings through the synthetic speech.

ACKNOWLEDGEMENTS

This work was supported by SERC Postgraduate Studentship 8631679X, SERC/MOD Research Grant GR/F 63862 and the Digital Equipment Corporation.

REFERENCES

1) Newell, A.F., Arnott, J.L. and Alm, N., "Developments Towards an Integrated Prosthesis for the Non-Vocal", Proc. 13th RESNA, 1990, pp. 97-98.

2) Swiffin, A.L., Arnott, J.L., Pickering, J.A. and Newell, A.F., "Adaption and Prediction Techniques in a Communication Prosthesis", Augmentative and Alternative Communication, 12/1987, pp. 181-191.

3) Alm, N., Newell, A.F. and Arnott, J.L., "A Communication Aid which Models Conversational Patterns", Proc. 10th RESNA, 1987, pp. 127-129.

4) Murray, I.R. and J.L. Arnott, "Towards the Simulation of Emotion in Synthetic Speech: A Review of the Literature on Human Vocal Emotion", paper to be published.

5) Murray, I.R., Arnott, J.L. and Newell, A.F., "HAMLET - Simulating Emotion in Synthetic Speech", Proc. Speech '88, 7th FASE Symposium, 1988, pp. 4:1217-1223.

6) Johnson, W.F., Emde, R.N., Scherer, K.R., and Klinnert, M.D., "Recognition of Emotion from Vocal Cues", Arch. Gen. Psychiatry, 43, 1986, pp. 280-283.

Iain R. Murray,
Microcomputer Centre,
Dept. of Mathematics and Computer Science,
The University,
Dundee DD1 4HN,
Scotland, UK.

20.3 Synthesized Spanish speech using letter-to-sound rules

Pamela Trittin and Richard Foulds
Applied Science and Engineering Laboratories
University of Delaware/Alfred I. duPont Institute
Wilmington, Delaware USA

Abstract

This article provides an explanation of work being conducted at the Applied Science and Engineering Laboratories of the University of Delaware and Alfred I. DuPont Institute. The purpose of this work is to provide a way for nonvocal, Spanish-speaking individuals to be able to communicate in a society which is predominately vocal by incorporating a text-to-speech program which uses Spanish letter-to-sound rules into a speech synthesizer.

Background/Statement of the Problem

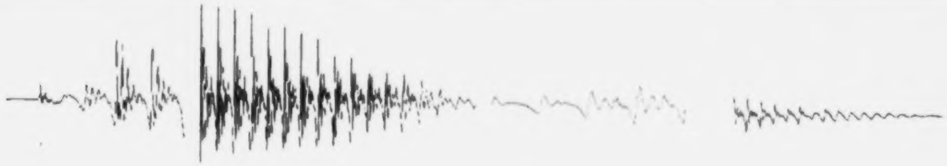
As the Spanish-speaking population in the United States continues to increase, so does the necessity for multilingual speech synthesis devices. Former methods to produce such a device simply alter existing English methodologies. One technique uses letter-to-sound rules of English and changes the spelling of the Spanish word, phrase, or sentence to obtain an approximation of the pronunciation in the Spanish language. Another method combines phonemes of the English language to estimate Spanish phonemes (Sherwood 1978). The result of applying these methods is Spanish speech which sounds very English-like since there are phonemes which cannot be represented by the English language.

Since the speech produced by the previously mentioned methods is unsatisfactory, an alternative method using a text-to-speech algorithm with letter-to-sound rules produces astonishingly natural results. Implementing a Spanish diphone library and letter-to-sound rules yields synthesized speech which reflects the natural qualities of the Spanish language. The resulting speech is a smooth sounding Spanish utterance. This method not only allows language-specific dialectical differences, but it also incorporates age and gender characteristics of the potential user.

Approach

Like the method used by Yarrington, Jones and Foulds, three steps are necessary to produce synthesized Spanish speech using letter-to-sound rules: (1) produce a Spanish diphone library, (2) create a Spanish text-to-speech program to convert Spanish text to synthesized speech, and (3) apply prosodic features before producing the final synthesized speech.

Step one involves creating an inventory of Spanish diphones. Typically a diphone library consists of at most $n^2 - n$ entries (n being the number of phonemes). There are roughly 28 phonemes in the Spanish language; therefore there are 756 diphones in the

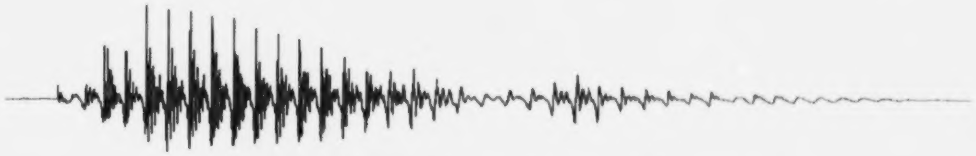


Diphone **#a** taken from the word *haba**

Diphone **ad** taken from the word *dado*

Diphone **do** taken from the word *dedo*

Diphone **o#** taken from the word *pago*



By concatenating the above diphones, the word *hado* is produced.

* The symbol # refers to a blank space.

inventory. This is an upper bound which eliminates repetitions; however *ee* and *oo* are added since there is an increase in either duration or pitch in words such as *creer* and *cooperar* (as was noticed while recording the voice of a Costa Rican native). Compared to the 1560 diphones necessary to create an English diphone inventory, the number of diphone library units in the Spanish library is a considerable decrease. It is, however, necessary to increase the size of the Spanish diphone inventory because the quality of liquids and glides (*l, w, r, rr*), and diphthongs (*ai, ao, oi*) is unsatisfactory unless they are concatenated as triphones instead of diphones. In other words, the surrounding phonemes are included when they are manually extracted. This increases the Spanish diphone library to a potential 5488 units. Many of these, however, are not found in Spanish. The current library consists of 895 diphones and triphones. Stored as time-domain waveforms, the diphones extracted from carrier-words make up the Spanish diphone library. In order to incorporate gender and age differences, diphone libraries are produced by recording male, female, and children's voices. Storing the diphones as time-domain waveforms retains the natural language qualities of speech normally lost through analysis (Yarrington, Schlemmer, and Foulds 1990).

The second step to create synthesized Spanish speech is to create a text-to-speech program. This program converts written Spanish text to speech using a pronunciation dictionary in addition to letter-to-sound rules. The dictionary is established to cut down the number of calls to the letter-to-sound rules. Included in this dictionary are not only Spanish words whose pronunciation violates the letter-to-sound rules but also frequently used words in the Spanish language obtained from a Spanish corpus. By including a suffix stripper to the algorithm, the size of the dictionary is reduced considerably since there is no need to add words containing certain suffixes to the dictionary: the root word is all that is necessary. Suffixes accounted for in this program include the following: *-ito, -ita, -illo, -illa, -ico, -ica, -uelo, -uela, -ete, -eta, -ísimo, -ísima, -ín, -ina*, and *-s*. With the help of the suffix stripper, the text-to-speech program outputs a symbolic representation of the inputted Spanish lexeme (or phrase or sentence). A speech device then takes this representation as input and produces an analog signal which is the synthesized Spanish speech.

The final step to produce Spanish speech involves prosodic features. Prosodic features applied to synthesized speech eliminates monotonous tendencies of synthesized speech produced through this text-to-speech program. Among these features are pitch, stress and duration of sounds. A prosodic program will assign values for these features based on the Spanish syllabification and stress assignment algorithms. The syllabifier program accomplishes these two tasks. Spanish words break down into syllables using nine fundamental rules, and three elementary rules govern the placement of stress. For example, if the incoming word is *amigo*, the program outputs **a.mi".go**. Adverbs ending in *-mente* receive one primary stress marker and one secondary marker: **u"t.il.me'n.te** is the result of inputting *útilmente*. Separating a word by syllables and applying stress markers provides a means to assign values to prosodic parameters to synthesized speech which ultimately produce highly intelligible speech.

Implications/Discussion

Prosocic features applied to synthesized speech together with a text-to-speech algorithm using Spanish letter-to-sound rules provide synthesized speech that is highly inteligible and natural sounding. It provides a means for nonvocal individuals to verbally communicate in this predominately vocal society.

This method produces exceptional, natural sounding speech output. The qualities of gender and age are preserved, and the output is highly comprehendible. Although the synthesized speech obtained is encouraging, there are drawbacks to this method . The main limitation to this method is that pitch is difficult to manipulate. This is because no analysis of the digitized speech and extracted speech segments is done; therefore, loss of natural speech qualities is kept to a minimum. Timing of an utterance also poses some problems to this methodology. Increasing the duration of phonemes which contain steady states is not a problem for this method: the pitch period of the steady state is simply repeatedly inserted. However, increasing the duration of phonemes which do not have clearly defined steady states as well as decreasing the duration of all phonemes are difficult to manipulate (Yarrington, Jones, and Foulds 1989). One way to overcome these drawbacks is to increase the number of diphones to include stressed and unstressed syllables. The diphone, *el*, taken from *papel* is stressed, but the diphone from *ángel* is not stressed. By including both stressed and unstressed diphones in the inventory, concatenation with the appropriate diphone should provide satisfactory results. This is a feasible option because the inventory for the Spanish language is nearly four times smaller than the English inventory, so the expense of almost doubling the Spanish inventory is not overwhelming. Only those diphones which contain vowels require stressed and unstressed carrier words. Further research and experimentation with this option will hopefully result in acceptable synthesized speech.

Acknowledgments

A grant provided by the United States Department of Education and Rehabilitation Engineering Center on Augmentative Communication (grant #HI33800015-90) supports the aforementioned work.

References

Navarro Tomás, Tomás. *Manual de pronunciación española*. 22nd ed. Madrid: Instituto Miguel de Cervantes, 1985.

Sherwood, Bruce Arne. "Fast text-to-speech algorithms for Esperanto, Spanish, Italian, Russian and English." Int. J. Man-Machine Studies 10 (1978): 669-692.

Yarrington, Debra, Jones, Mark, and Foulds, Richard. "New Methods for Pitch Change During Time-Domain Waveform Coded Diphone Speech Synthesis." RESNA Conference 1989.

Yarrington, Debra, Schlemmer, James, and Foulds, Richard. "Improvements in Synthesized Speech Using Time-Domain Waveform Coded Diphones." AVIOS Conference 1990.

Contact

Pamela Trittin
Applied Sciences and Engineering Laboratories
A. I. duPont Instute
PO Box 269
Wilmington, DE 19899
Email: trittin@asel.udel.edu

A STRATEGY FOR GESTURAL CONTROL OF SYNTHETIC SPEECH 20.4

David M. Horowitz

Department of Mechanical Engineering
Massachusetts Institute of Technology

Department of Rehabilitation Medicine
Tufts University School of Medicine

Abstract

There is a growing interest among computer scientists to devise methods by which people can interact with a computer through a combination of manual, visual or facial gestures. For individuals who are unable to speak, a gestural method of communication may offer a more efficient method of communication. If the method of communication can be translated by computer to produce synthetic speech, the requirement that other individuals know the gestural language is eliminated. A strategy for gestural control over synthetic speech has been developed as an alternative to keyboard based augmentative communication. The gestural method interprets a gesture indicated by the user through an appropriate input device as a syllabic utterance in English which in turn is acoustically synthesized. The strategy includes an orthographic representation of English that takes into account the phonotactic constraints on English syllable structure in order to minimize the complexity and time associated with the production of a syllabic utterance.

Background

There are approximately 1.5 million children and adults in the USA who are unable to speak due to neuromuscular impairment [1]. For those individuals whose motor ability is intact, manual sign language may be used. Sign Language, such as American Sign Language (ASL), has the advantage of allowing the user to communicate at a rate commensurate with conversational English by gesturing.

For those who are both non-verbal and motor disabled, the extent of their physical disabilities significantly reduces their ability to accurately produce the gestures of ASL. However, individuals within this group possess a wide range of limited motor ability and many are able to use some form of communication board or device to augment their communicative ability. Work on gesturally based methods of augmentative communication is based upon the hypothesis that a system which can reliably interpret an individual's repeatable gestures may provide the individual with a more efficient method of communication. *Gesture is broadly defined to mean any continuous manual motion or set of motions with communicative intent.* Gesturally based communication may be grouped into two approaches: **gesture recognition** and **phonotopic.**

A **gesture recognition** system learns and subsequently recognizes the free limb and head movements of individuals who are both non-verbal and motor disabled [2,7,8]. This approach applies commercially available position monitoring systems to monitor a point on either a limb or the head. These movements are analyzed with the intent to harness the repertoire of gestures available to a particular subject and to develop a method for computer recognition of these gestures. Presumably the repertoire of gestures could subsequently be mapped to various functions for control of computer based devices.

A **phonotopic** system is based on a representation of speech captured in a computer display. Phonotopic refers to a topological arrangement of phonemes. Gestures are indicated by passing a pointer through the display to select targets using a position monitoring device. In this case, a gesture corresponds to a syllabic utterance. A phonotopic system encourages the user to associate a particular gesture with a speech utterance. The goal is to provide an individual with a method of control over synthetic speech which allows the individual to develop a proprioception or tactile-kinesthetic association of the parameters of speech much in the same way a keyboard allows a pianist to develop a proprioception of music.

Although not intended for augmentative communication, phonotopic interfaces to speech synthesizers have been demonstrated as early as 1960 [4]. By manipulating the first and second formants of speech, Gunar Fant demonstrated an analog speech synthesizer which could produce vowel utterances. For example, it was possible to produce a set of utterances which sounded like "I love you" since consonants do not play as crucial a role as vowels in the intelligibility of this phrase. By passing a pointer through a space defined by the two formants (one axis representing the first formant and the other axis representing the second), Fant could indicate the phrase through a "gesture".

Recently, Girson and Williams [6] have proposed an articulator based method of control over synthetic speech. An articulator based method of control involves simulating various positions and motions of the tongue and vocal tract by controlling a trajectory through a space and by pressing a set of switches. This method of control can be termed a manual articulator and involves specifying several parameters which comprise a single phoneme or speech sound. Paradoxically, the authors reject a phoneme based method of control because it is too burdensome. However, their approach requires the control of several parameters to generate a single phoneme.

Statement of the Problem

To date, no empirical approach has been discussed in the literature concerning the design of a phonotopic gestural communication system. This paper discusses one strategy which organizes the phonemes in a display according to natural constraints governing English syllable structure. The hypothesis is that by applying the known phonotactic constraints on English syllable structure to the design of a gestural system, an added dimension of control over synthetic speech is provided to the non-vocal individual.

Approach

The sequence of consonants and vowels during the course of an utterance in English is highly constrained by the rules of syllable structure. These rules are determined in part by the fact that the production of sequences of syllables involves alternate opening and closing gestures in the vocal tract, with vowels occurring during the open phases and consonants or consonant sequences occurring during the constricted phases. Syllable-based constraints are utilized in the approach reported in this paper to simplify an individual's control over a speech synthesizer. The control procedure requires the user to execute one gesture or motor act for each syllable. The user indicates a syllable by selecting targets in the display. The rate of communication is enhanced by designing the display to minimize the time it takes to indicate a syllable. Once an utterance is indicated, it is acoustically synthesized by a speech synthesizer.

The approach presented in this paper utilizes the syllable as the unit of speech production, rather than a larger unit such as a word or phrase, or smaller unit such as the phonetic segment. If every phoneme is captured in the display, the benefit of a phonotopic syllable-based approach is that the user can express an unlimited vocabulary. There have been very few attempts at developing a syllable-based communication system. Most notable is the WRITE system [5]. WRITE is based on a statistical approach which captures the most frequent syllables occurring in a 100,000 word corpus of conversational English.

As an example of a spatial arrangement that takes advantage of the structure of a syllable, one might imagine a circular region in a plane. The selection the user makes for each syllable has some similarity to the "manner" a speaker uses to produce a syllable with the intact speech apparatus. Vowels (corresponding to the open phases of the vocal tract during utterances) form the nucleus or central portion of the syllable. They are represented more centrally in the circle. Consonants that tend to be at the beginning or end of a syllable would be more peripheral, while consonants that can occupy a non-terminal position (such as [r] and [n] in the word print) would be located more centrally in the circle, but not as central as the vowels. In this way, the user could make selections for a consonant cluster without having to make a sharp change in the direction of the movement.

In addition to syllable based constraints, the statistics of spoken English need to be considered as well. While syllable based constraints help define the relative location of phonemes in the display, there may be several phonemes competing for a particular position during the course of an utterance. Application of the statistical characteristics of spoken English helps to order the set of phonemes. Denes [3] reports on the statistics of spoken English. These statistics are examined to determine the location of phonemes in the display. The placement of each of the phonemes is governed by the goal to minimize the effort expended by the user to indicate two likely co-occurring phonemes. More frequently occurring phonemes are positioned in locations which are easily accessed by the user while less frequently occurring phonemes are placed otherwise.

The geometry of a phonotopic display must also take into account biomechanical constraints. Consider as an example, a display which is to be navigated by a hand-held mouse. The mechanics of human arm motion help define the constraints according to which phonemes are positioned in the display. Given the fact that certain trajectories are easier to perform than others, the goal is to place most frequently occurring phoneme sequences along the trajectories which are the easiest to produce. Rosen *et al.* [9] report results of a motor assessment of 11 motor-disabled subjects and 16 able-bodied subjects. The results revealed a systematic dependence of movement time on distance, and a strong and sometimes regular variation of movement speed with direction. The dependence of movement time is describable in biomechanical terms: individuals are slowest in the directions which require nearly pure shoulder motion and fastest in the orthogonal direction. For example, a right handed individual would exhibit the fastest motions from the left lower quadrant to the right upper quadrant.

Implications

The approach described above identifies some constraints which can be applied toward the development of a gestural interface for synthetic speech. Although the approach described above was applied to a standard mouse, it may be applied to other position monitoring devices as well. Unlike the approaches which attempt to recognize unconstrained gestures [e.g. 7], the approach proposed in this paper adds constraints which may aid in the evaluation of the feasibility of using continuous gestures as an alternative or added input modality to augmentative communication. For similar reasons to the ones discussed by Rosen and Trepagnier [9] arguing for the need to systematically evaluate the layout of a keyboard based communication device, a systematic approach is required for evaluating communication techniques which make use of continuous gestures through position monitoring devices. A thorough approach requires the development of assessment techniques for use of continuous input devices such as the mouse, joy-stick, head mouse, Polhemus and data-gloves which provide added degrees of freedom. In rehabilitation, there is an active interest in evaluating these input modalities. A systematic approach is required, given that the way in which these devices will be utilized is highly dependent on the individual motor characteristics of the user as well as the functional characteristics of the particular application.

Discussion

The approach discussed in this paper presented one layout for a phonotopic display to be controlled by mouse gestures. Consonant clusters represent a particular challenge for this type of display. In order to keep mouse trajectories smooth, consonant clusters must be located more centrally in the space. However, this could result in complex trajectories for the production of syllables without consonant clusters. The user would have to avoid consonants located more centrally in the display in order to go directly from a syllable-initial consonant to a vowel. The use of a pressure sensitive device might provide a useful alternative to the mouse in this instance. By representing syllable-initial and syllable-final consonants and vowels in the same plane in the display and by locating those consonants which follow the syllable initial consonant or precede the syllable final consonant in receding planes, users might need only apply pressure during the course of an utterance in order to invoke the consonant cluster. This approach may result in a display which maintains the smoothness of trajectories for a maximal number of utterances.

Adding a pressure sensitive device provides the designer of the display with an additional degree of freedom. The additional degree of freedom allows for a possible increase in the rate of information transmission. If each degree of freedom is treated as an independent channel of information, additional degrees of freedom mean that fewer phonemes need to be mapped to any single degree of freedom.

An alternative to layering the display which requires a pressure sensitive device would be to selectively deactivate targets on the display based on the user's selection process. This approach is similar to the work being done in prediction in that it requires predictive techniques in order to determine which targets are likely to be selected next. Phonotactic constraints can also be utilized in this instance to simplify the selection process. Certain non-initial or non-final consonants can immediately be de-activated based on the selection process (as an example, if /s/ and /t/ are selected, /l/ is not a possible next alternative). Another approach to improve the display would be to employ language units which are groups of phonemes such as the language units employed in WRITE [5]. Finally, several alternative approaches to the single point trajectory might be taken. By utilizing a glove which could measure hand posture and position, several added degrees of freedom are provided. Work is underway at the MIT Media Laboratory Computer Graphics Animation Group to evaluate emerging glove technologies to allow users to interact with 3-dimensional graphical environments. An approach which utilizes glove technology for control of synthetic speech need not adopt sign language conventions. For example, Sturman, Zeltzer and Pieper [10] have evaluated the hand as a valuator (a polled device that returns a continuous scalar value). Typical valuators are sliders and dials. Mice often are used as valuators by examining only one degree of freedom. Sturman *et al.* point out that the DataGlove from VPL research (Redwood City, CA) returns 10 values representing the angles of the finger joints and six values representing the position and orientation of the back of the hand. Taken separately, these values can be used as valuators. However, it is questionable if an individual with motor impairments could utilize all values. This needs careful evaluation, but it is anticipated that a subset of the values could be utilized by some individuals, providing a possible increase in the rate of communication.

Part of the motivation for this work was the observation that gestural methods of communication enable deaf individuals to communicate at a rate equivalent to the rate of conversational speech. The goal of this paper was to present an approach to help motor disabled non-vocal people utilize their limited repertoire of gestures as a method for generating synthetic speech. ASL is not appropriate for individuals with motor impairments. Furthermore, these individuals usually have normal hearing and acquire competence in English. Requiring individuals who understand English to learn a new gestural language with a new grammar such as ASL is questionable. This motivated the design presented in this paper with a single point trajectory serving as a control signal through a phonotopic space. Clearly, the feasibility of this approach remains to be demonstrated in clinical trials. Experiments are underway to help evaluate this approach. Assessment techniques are currently being developed for the mouse and the data-glove as input devices.

References

[1] ASHA (1981). Position Paper for the Ad Hoc Committee on Communication Processes for Nonspeaking Persons, American Speech and Hearing Association, Rockville, MD.

[2] Cairns, A. (1989). "Computer interpretation of gestures made by the severely disabled.", published abstract, Rehabilitation R&D Progress Reports, Vol. 26, pp 187-188.

[3] Denes, P. (1964). "On the statistics of spoken English", The Journal of the Acoustical Society of America, Vol. 35, No. 6, pp 892-904.

[4] Fant, G. (1960). Acoustic Theory of Speech Production (Mouton, 's-Gravenhage, The Netherlands).

[5] Goodenough-Trepagnier, C. and E. Tarry (1982). "Derivation of an efficient,nonvocal communication system", Human Factors, 24(2), 163-172.

[6] Girson, A. and R. Williams (1990). "Articulator-based synthesis for conversational speech", Proceedings of the IEEE International Society of Acoustics, Speech and Signal Processing, pp 873-876.

[7] Harwin, W.S. and R.D. Jackson (1990). "Computer recognition of head gestures in cerebral palsy", Proceedings of 13th Annual RESNA Conference, pp 257-258.

[8] Nantais, T., M. Milner and F. Shein (1988). "Gestural predictive control system for non-speaking persons", published abstract, Rehabilitation Engineering Department Annual Report, The Hugh MacMillan Medical Centre, p 91.

[9] Rosen, M., C. Goodenough-Trepagnier, C. Getschow, and T. Felts (1986). "Qualitative aspects of Fitts task performance by motor-disabled individuals", Proceedings of the 9th Annual RESNA Conference, pp 161-163.

[10] Sturman, D., D. Zeltzer and S. Pieper (1989). "Hands-on interaction with virtual environments", Proceedings of the Association of Computing Machinery SIGGRAPH, pp 19-24.

Acknowledgements

This work was supported on a National Institute of Disability and Rehabilitation Research Advanced Rehabilitation Career Traineeship Grant #H133P90005-90. Additional support for this work was provided by a Rehabilitation Service Administration Grant Special Projects and Demonstration Grant #H128A01011.

The author would like to thank Profs. Robert W. Mann and Kenneth N. Steve[illegible]eir open-minded support of this work. Special thanks [illegible]e Rosen and Cheryl Trepagnier for their comments.

Address correspondence to:

David M. Horowitz
Department of Mechanical Engineering
Room 3-137A
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, MA 02139

20.5

THE CANDY PROJECT: GESTURE-DRIVEN SPEECH SYNTHESIS

Ronald D. Williams, Electrical Engineering
Randy Pausch, Computer Science
School of Engineering and Applied Science

Janet H. Allaire, Speech and Hearing
Laura K. Vogtle, Occupational Therapy
Kluge Children's Rehabilitation Center

University of Virginia
Charlottesville, Virginia

INTRODUCTION

The CANDY project (Communication Assistance to Negate Disabilities in Youth) is a ten-year effort to create a conversational speech synthesizer for use by individuals who have cerebral palsy. This project is currently in its third year, and several preliminary results have been obtained. Research on this project involves a cooperative effort among electrical engineers, computer scientists, speech and hearing specialists, and occupational therapists. This paper describes the directions of the CANDY project and presents progress thus far.

THE PROBLEM

To be effective, speech communication must exhibit both fluidity and spontaneity. It is precisely this "conversational" quality of speech that is missing in existing speech synthesis systems. Existing systems are typically different variations on text-to-speech synthesizers, and this approach can offer fluidity while it severely limits the spontaneity available to the user.

Speech requires both volitional and refined movements and symbolic thought. Symbolic thought determines message content, and the nervous system then controls the muscles in the vocal system to create speech. Certain medical conditions limit the ability to control the vocal system even though symbolic thought remains. People who exhibit these problems are unable to participate in conversational speech. Since everyday functioning normally depends on the ability to speak, these individuals can be severely hindered and frustrated. Therefore, the overall goal of this project is to provide a synthetic speaking device that can be controlled by these users to produce conversational speech.

The target population includes individuals who retain the thought processes necessary for conversational speech but who lack the control of the vocal system necessary to produce this conversational, intelligible speech. Preliminary research has focused on the particular target population consisting of children with cerebral palsy and severe speech impairments. This may be a limited potential user group, but the preliminary work completed thus far can be applied to a much larger target population.

To be completely successful, a speech prosthesis must be fast, efficient, and intelligible. That is, it must be conversational. Being conversational implies a device capable of producing high quality speech based on real-time inputs from the user. Unfortunately, most state-of-the-art interfacing techniques are too limited for a user to operate at conversational rates. An example is a picture board that relates pictures to utterances. Picture boards require visual scanning and linking pictures, and this can be a slow process. Also, most current speech synthesizers exhibit high-quality performance only if the speech to be synthesized is known in advance. For example, text-to-speech synthesizers take pre-stored text, process it and synthesize it. No prior knowledge of the current speech will be available for this real-time device. Therefore, for this new device to work, new interfacing and synthesizing techniques must be found, and these techniques must be implemented in ways to allow different users to create conversational speech.

There are three fundamental questions of project feasibility:

(1) Is it possible to build a speech synthesizer to generate conversational speech based on limited real-time inputs from a user?

(2) Is it possible to build an interface that will permit the capture of the necessary real-time inputs?

(3) Is it possible for individuals in the target population (or any individuals, for that matter) to provide the controls necessary to drive such a speech synthesizer?

Affirmative answers for all three questions are required for the premise of this work to be supported.

This paper presents the concept of the CANDY project and offers preliminary results of research addressing the first two of these fundamental questions. First, a brief review of the physical processes involved in speech production is offered to establish a basis for this work. This section is followed by a description of the articulator-based synthesis technique used in the CANDY project. Next, the interface is described. Finally, we offer a few words about the future of the project.

PHYSICAL SPEECH PRODUCTION

The physical process of speech production can be divided into three sequential stages. First, air is forced through the vocal cords to produce either a voiced or unvoiced glottal excitation. Next, the air flow is modified by a series of intricate structures that can be collectively called the vocal tract resulting in articulation. Finally, the modified flow is radiated through the lips and nostrils [1].

The initial excitation is accomplished by expelling air from the lungs between the vocal cords. To produce a voiced sound, the cords oscillate with a specified frequency. Changing this frequency will result in a higher or lower pitch for a sound [2]. For unvoiced excitation, the vocal cords are held apart to allow the air from the lungs to flow continually between them. Unvoiced excitation can be thought of as a white noise source.

After the flow of air passes through the vocal cords, the specific properties of the different sounds must be generated. These properties are produced through changes in the air flow in the vocal tract.

The vocal tract changes size and shape to reinforce certain frequencies and attenuate others by moving the articulators of speech: the tongue, jaw, lips, and velum. Specific positions for these articulators correspond to different spectral characteristics, and therefore to different sounds [2].

To change a sound, the articulators are moved from one position to another in continuous motions that give speech its continuous, conversational quality.

The tongue is the most important articulator. The jaw, lips, and velum play a less important role in shaping the speech spectrum [2].

The articulators in the human vocal tract exhibit many degrees of freedom, and the coordinated motion of these articulators produces fluid, conversational speech. Human speech is produced as the composition of continuous sounds. The character of these sounds at each instant in time is determined by the instantaneous configuration of the articulators in the vocal tract. The fact that articulator motion is concerted is fortunate because in effectively reduces the number of parameters specifying the state of the vocal tract, providing hope that a control signal with limited degrees of freedom can be used to drive a continuous speech synthesizer.

Conversational speech can be inhibited by the transfer of symbols across the user interface. While the mental production of speech may be principally a symbolic process, the generation of speech sounds in the human vocal tract is physical and continuous. Our hypothesis is that if speaking persons can control their complex vocal tract at conversational rates, then many non-speaking individuals should be able to control a simplified simulated vocal tract to synthesize speech at conversational rates. We expect that the users may require much time to learn to control this unique speech prosthesis, as the learning process can best be compared to the steps required for children initially learning to speak.

ARTICULATOR-BASED SYNTHESIS

The primary objective of the CANDY project is to develop an alternative to the conventional symbol-based speech synthesis approach. This approach moves entirely away from linguistic symbols at all levels and instead offers the user a synthetic vocal "instrument," analogous to a musical instrument. The user interface accepts motions that loosely correspond to the motions of vocal tract articulators.

The CANDY prototype speech synthesizer uses a parallel formant synthesizer based on a modified Klatt Formant Synthesizer [4]. This synthesis approach is used in several high-quality systems such as the MITalk and DECtalk Speech Synthesis Systems [4][5]. This approach allows control of the source and vocal tract characteristics that are central to the implementation of the articulator-based system.

Formant synthesis offers several advantages for this project. Frequency, bandwidth, and amplitude parameters are used to derive a set of coefficients for each formant. For a given utterance, sets of these formant-based coefficients can be used to synthesize the speech [1]. Slight changes in the parametric formant data will alter certain prosodic components of speech [6]. Other prosodic components can be modified by changing the excitation. Formant synthesizers use data that can be processed before synthesis to permit their use in an input scheme based on the articulators of speech.

A severe constraint is imposed upon the synthesizer by the limited number of driving inputs that can be expected from the human user. Normal speech production within the human vocal tract involves the coordinated motion of several articulators exhibiting many degrees of freedom. It is very unlikely that any individual will be capable of replicating the full richness of this complex motion through tightly coordinated motions of various extremities. Therefore, some mapping must be established between that motions that can be produced by a user and the controls for the simulated vocal tract.

The initial prototype synthesizer focused only upon the motions of the tongue reduced to two degrees of freedom. Since the tongue acts as a continuous modifier of speech sounds, its motion can be modeled as a set of analog signals. These signals represent the control of specific muscles in the vocal tract that move the tongue to its proper configuration for a specified sound. The number of signals must be small, but one signal alone is not enough to model the complexities of the tongue. Physically, the tongue can be simplified to a movement of its tip and base, where the tip is the most mobile of any of the articulators [2]. The tip and base can be mapped onto an orthogonal two-dimensional space where motion along one axis represents the tip, and motion along the other axis represents the base. In this way, the tongue tip and base can move independently by holding one dimension constant, or together by varying the position along both axes. One such mapping grid is illustrated in Figure 1.

Movement of the tongue in the vocal tract alters the shape of the tract, and this alteration changes the formant data for the tract. Since all essential speech sounds correspond to particular positions of the tongue, these sounds correspond to certain formant parameters. Therefore, tongue positions can be mapped to corresponding formant parameters that can be used to synthesize the speech sounds. Overall, the system becomes an articulator-based formant speech synthesizer driven by voicing excitation and tongue position inputs.

It is important to recognize that the sounds placed upon the mapping grid of Figure 1 are not symbols. They are simply sounds that occur when the simulated vocal tract is in the configuration corresponding to the position on the grid. Words and phrases are constructed with motions across this grid surface just as speech is produced with motions of articulators through the vocal tract volume.

THE USER-TAILORED INTERFACE

Our current approach for capturing and processing user motions involves three-dimensional tracking

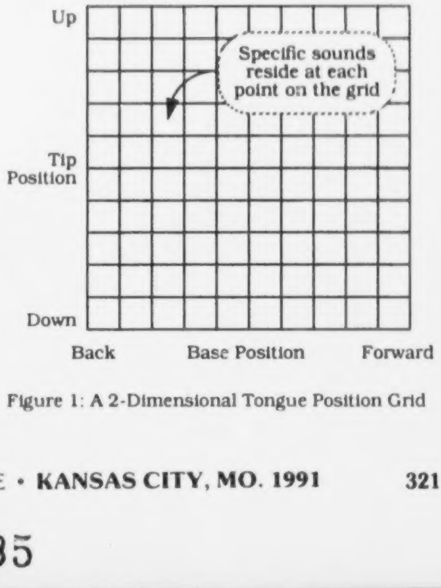


Figure 1: A 2-Dimensional Tongue Position Grid

coupled with the creation of custom projections to the two-dimensional tongue grid for each user. The most obvious advantage of this approach is that we can tailor the interface to each individual's best range of physical motion. Another advantage is that no strength is required to move a physical device as is needed in current interfaces. For the CP community, another advantage is that less coordination is required with our interface; with a physical interface, the user much first contact the device, and then move it in some way. The final advantage is that a software interface based on motion tracking can be adapted over time to account for improvement and/or fatigue.

Existing work on mapping gesture into continuous control signals is application dependent. For example, detailed tracking is performed in three dimensional drawing or sculpting applications [7], and virtual reality systems [8], where various three-dimensional signals [9] are mapped into motions in synthetic worlds shown on traditional or head-mounted displays. These systems perform mappings from position and orientation information, but the mappings are significantly less complicated than those needed for the CANDY project.

Our experimental setup uses one or two magnetic trackers attached to the subject at locations determined by a therapist. If only one tracker is used, the mapping problem reduces to mapping a six-dimensional signal (x, y, z, azimuth, elevation, roll) into a two-dimensional signal. There are two possible ways that two trackers can be used. In the first case, they both generate independent data, and the problem becomes a mapping from twelve dimensions to two dimensions. A second use of dual trackers is to use one as a base for the other. For example, if we are measuring head motion relative to the neck, and the subject tends to rock or raise his torso, we may attach the second tracker to the neck and use it as a base to compute the relative motion of the first tracker

The signals from the trackers are sent via a high-speed serial connection to the mapping computer. Mapping visualization information and interactive controls are provided for the therapist performing the tailoring. The continuous signals produced by the mapping are then applied to drive the synthesizer. Because the speech synthesizer is a complicated interface to master, we are currently using simpler one and two dimensional graphical applications with our disabled users.

Mapping consists of two basic phases. The collection phase determines the comfortable and preferred motions for the user. The control phase performs real-time mapping of user motion based on a mapping function created from the data obtained during the collection phase. The mappings we create are biomechanically comfortable for each user and easily learned through practice. As the candidate mapping is being used, users notice the results of their motions and experiment to discover the nature of the mapping, rather than having it taught to them by the therapist.

PROJECT STATUS

A prototype synthesizer has been constructed based upon the general grid structure illustrated in Figure 1. Work is currently progressing in two directions to improve this synthesizer. One effort is attempting to determine the optimum placement of sounds on this grid subject to both physical and linguistic objectives. A second effort is exploring the flexibility that can be gained through the introduction of a dynamically changing grid. Such a grid produces sounds depending upon both the location and the history of motion.

A prototype interface mapping system has been developed and it is currently being improved to enhance the flexibility of tailoring available. Experimentation with virtual reality may permit the therapist to be immersed into the control space of the user to support visual manipulation of the space. Limited subject trials have progressed to the stage where initial data collection has started.

REFERENCES

[1] L. Rabiner and R. Schafer, *Digital Processing of Speech Signals*, Prentice Hall, Englewood Cliffs, NJ, 1978.

[2] W. Zemlin, *Speech and Hearing Science*, Prentice Hall, Englewood Cliffs, NJ, 1968.

[3] A. Bronstein, *The Pronunciation of American English*, Prentice Hall, Englewood Cliffs, NJ, 1960.

[4] D. Klatt, "Software for a cascade/parallel formant synthesizer," *Journal of the Acoustical Society of America*, vol. 67, March 1980, pp. 971-995.

[5] J. Allen, M. Hunnicutt, and D. Klatt, *From text to speech: The MITalk System*, Cambridge University Press, Cambridge, U.K., 1987.

[6] T. Takagi and H. Kuwabara, "Contributions of Pitch, Formant Frequency and Bandwidth to the Perception of Voice-Personality," *Proceedings of the IEEE International conference on Acoustics, Speech, and Signal Processing*, 1986, pp. 889-892.

[7] C. Schmandt, "Spatial Input/Display Correspondence in a Stereoscopic Computer Graphic Work Station," *Computer Graphics*, vol. 17, no. 3, July 1983, pp. 253-261.

[8] S. Fisher, M. McGreevy, J. Humphries, and W. Robinett, "Virtual Interface Environment for Telepresence Applications," *Proceedings of the Human Factors Society 32nd Annual Meeting*, October 1988.

[9] J. Foley, "Interfaces for Advanced Computing," *Scientific American*, October 1987, pp. 127-135.

ACKNOWLEDGMENT

This work has been supported in part by the United Cerebral Palsy Foundation and by the Virginia Center for Innovative Technology.

ADDRESS

Ronald D. Williams
Department of Electrical Engineering
University of Virginia
Charlottesville, VA 22903-2442

FROM VOICE TO SIGN LANGUAGE: A TRANSLATION TOOL FOR THE WORKPLACE

Richard D. Amori, Phyllis A. Williams, and Susan Rohde
Computer Science Department
East Stroudsburg University
East Stroudsburg, PA

Abstract

To aid communication between hearing-able supervisors and their hearing-impaired employees, a prototype system has been developed which accepts spoken Engish and converts it into a video display of the language most readily understood by many of the hearing-impaired: ASL (American Sign Language). The system is compact, efficient, and constructed with low-cost, off-the-shelf hardware components. It demonstrates that a communication aid can be created for a vocational setting, using an approach which has potential for other areas of hearing-able/hearing-impaired communication.

Keywords: American Sign Language, natural language processing, spoken English, artificial intelligence

Introduction

American Sign Language is used by between 250,000 and 500,000 hearing-impaired people in the U.S. and Canada (4). It is a language which differs from English not only in its mode of expression but in its structure as well. With its different set of grammatical rules, ASL requires as much effort to learn as any other foreign language such as French or Chinese. Likewise, for many hearing-impaired individuals, written English is a foreign language requiring considerable effort to understand. Consequently, communication between the hearing-impaired and the hearing-able is often difficult.

Research Question

Could an automated system be constructed which would allow English speakers to communicate with the hearing-impaired in the workplace? Recent advances in computer hardware and software (voice recognition systems, videodisc systems, and natural language processors) suggest that such a tool might be constructed, and that it would be affordable. Even a tool for one-way communication would be an improvement.

We have designed and built a prototype of such a system for a real-world vocational domain, that of a metal-working shop. The system, Computer-Aided Sign Language (CASL), is designed to:

- accept English input through a microphone (a work-related sentence or phrase)
- translate the input into ASL-like text using a set of ASL grammar rules
- access the appropriate signs from video sequences of human signing stored on a random-access videodisc
- display the signs on a television screen.

Background

Our artificial intelligence laboratory has had a long-standing interest in computer understanding of natural language. Several research projects have been successfully carried out:

- a tool for building English-language interfaces (1)
- an English language understanding system for controlling robots (2)
- a system for interpreting complex spatial commands.

The potential offered by such language understanding systems for serving the physically disabled was described at an earlier RESNA conference (3).

Linguists have studied the structure of American Sign Language in depth in recent years (4, 5). But automating the translation of English into ASL has received very little attention. Some elementary work in sign language animation has been done (6), without addressing the grammatical differences between the two languages, the pervasive problem of ambiguity in English words, and the need for custom-designed vocabularies. As far as we know, CASL is the only attempt at constructing an integrated voice-to-video system which accepts job-related English and produces sign language in which the ambiguities have been resolved and the structure reflects the grammar not of English but of ASL.

Methods

The prototype system was designed for the metal-working shop at the Tobyhanna Army Depot in Tobyhanna, PA. Language data was collected by interviewing the hearing-able supervisors and hearing-impaired employees in the shop and audiotaping task-oriented language for linguistic analysis.

From the language data, a vocabulary of about 800 phonetic "words" was defined for the voice recognition system, with homonyms such as "for"/"four" listed as single entries, and inflected forms such as "gave"/"given" listed separately.

Translations at the sentence level were arrived at through consultation with professional ASL interpreters, textbooks on ASL (4, 5), and a sign language instructor. Translation rules, incorporating syntactic and semantic features of both languages, were then implemented in software. Special attention was given to providing accurate translations of homonyms, using contextual clues to clarify the intended meaning. In a voice input system, the problem of ambiguity is aggravated by the lack of spelling clues. Examples of CASL translations are provided below.

A sign vocabulary of about 450 signs was defined and videotaped, with one of the hearing-impaired employees from the shop serving as actor. The videotape was then loaded onto a videodisc to allow random access to each sign.

Software interfaces for the input and output devices (voice recognizer and videodisc player) were written, and the system was integrated. The hardware components of CASL are shown in Figure 1.

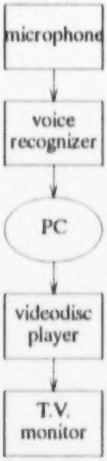


Fig. 1

Results

The following annotated transcript of a CASL session illustrates some of its translation features. The English input appears in quotes; the sign translation is represented by words in upper case.

"Countersink the screws a half inch." -->
COUNTERSINK SCREW HALF
(Articles and the plural ending have been dropped, along with the word "inch", which in this context is superfluous.)

"Did you get the work-order?" -->
YOU GET FINISH WORK-ORDER QUES-MARK
(Past-tense inflection "FINISH" follows verb. Question is indicated by sign for question mark.)

"Where's the other five?" -->
WHERE OTHER FIVE WHERE
(Ungrammatical English is accepted. Interrogative sign "WHERE", repeated for emphasis, makes question mark superfluous.)

"Doesn't this fit?" -->
THIS NOT FIT QUES-MARK
(Word order of negative question is rearranged.)

"We worked yesterday." -->
YESTERDAY WE WORK
(Time expression "yesterday" is translated first. Since time context is then established, past-tense verb inflection is not needed.)

"We're leaving on Monday." -->
MONDAY FUTURE WE LEAVE
(Time phrase "on Monday" is translated first. Word order of phrase is reversed, and translation of "on" is based on verb tense.)

"We left on Monday." -->
MONDAY PAST WE LEAVE
(Different verb tense results in different translation of "on".)

"We left." -->
WE LEAVE FINISH
(Past-tense verb inflection is needed in absense of time expression.)

"The hammer is on the table-saw." -->
HAMMER ON TABLE-SAW
(Translation of "on" is based on spatial meaning. Since sense is spatial, not temporal, phrase can be left at end.)

"Rite this on the rite side rite now." -->
NOW WRITE THIS ON RIGHTHAND SIDE
(Ambiguity is resolved by using contextual clues.)

The system is a working prototype which was well received when it was demonstrated to the hearing-impaired employees and their supervisors at the metal-working shop. It now needs an extended period of on-site testing and evaluation.

Implementation Data

CASL is written in Pascal and consists of about 4,000 lines of code. About 5 person-months were required to design and code the prototype system.

CASL runs on an IBM-compatible PC (286 chip) under DOS. Voice recognition is handled by

Dragon's "DragonWriter" DW-1000. The sign language images are stored on a Technidisc videodisc, accessed by Pioneer's "LaserVision Player" LD-V8000, and displayed on an NTSC-compatible TV monitor. The total hardware cost was approximately $11,500, a figure which will undoubtedly decline in the future.

The response time to translate a sentence from English text to ASL-like text is instantaneous. Another second or less is required to extract each sign from the videodisc for display on the TV monitor.

Discussion

The work-related English which the system accepts is broad and rich - a large and often ambiguous vocabulary and a variety of expressive modes (commands, questions, declaratives, and sentence fragments). Yet the software is compact and efficient, and the hardware components are widely available and affordable.

This proof-of-concept prototype demonstrates that a practical system can be developed for translating spoken English into ASL in a well-defined domain. Such a system has great potential not only in vocational settings but in educational settings as well - for example, as a tool for tutoring hearing-impaired students and as a tool for teaching ASL to the hearing-able.

Acknowledgements

This research was supported by a grant from the Ben Franklin Partnership, Commonwealth of Pennsylvania. We also thank Donnelle Denery (Tobyhanna Army Depot), Nancy Kosteleba (Luzerne County Community College), and Debra Maltese (Scranton State School for the Deaf and later Northeast Regional Office of the Deaf and Hearing-Impaired) for their assistance.

References

1. Amori, R., *NL/Template: an Approach and Tool for Building Practical Natural Language Interfaces*, Proceedings of the Annual Conference of the Association for Computing Machinery, ACM-85, Denver, CO, October 1985
2. Amori, R., *A Natural Language Interface for Task-Oriented Activities*, Proceedings of the Third International Conference on Industrial and Engineering Applications of Artificial Intelligence and Expert Systems, Association for Computing Machinery, IEA/AIE-90, Charleston, SC, July 1990
3. Amori, R., *TODUS: a Natural Language Interface with Potential for Rehabilitation Applications*, Proceedings of the Annual Conference on Rehabilitation Technology, RESNA-89, New Orleans, LA, June 1989
4. Baker, C. and Cokely, D., *American Sign Language: a Teacher's Resource Text on Grammar and Culture*, T.J. Publishers, Inc., Silver Spring, MD, 1980
5. Humphries, T., Padden, C., and O'Rourke, T.J., *A Basic Course in American Sign Language*, T.J. Publishers, Inc., Silver Spring, MD, 1980
6. Microtech Consulting Co., *CAV-ASL*, Cedar Falls, IA

Richard D. Amori
Computer Science Department
East Stroudsburg University
East Stroudsburg, PA 18301

A MODULAR SOFTWARE SYSTEM FOR CONTROLLING AN OPTACON-COMPUTER INTERFACE

Karsten A. Loepelmann & Eugene C. Lechelt
Department of Psychology
University of Alberta
Edmonton, Alberta, T6G 2E1, CANADA

ABSTRACT

We have developed an interface for a tactile vision-substitution system to address basic and applied issues in tactile stimulus information processing. The system is comprised of an OPTACON (OPtical-to-TActile CONverter, a reading aid for the blind) interfaced to an IBM microcomputer running custom software. The OPTACON presents tactile stimuli to the distal pad of the left index finger via a 6x24 tactual matrix (1). The unique feature of the system is a modular software interface, designed to be highly flexible and easy to use, thus facilitating development of software for research. Examples of the different display modes the software is able to generate are given. Limitations of stimulus presentation are discussed, as are applications of the software in addition to research.

BACKGROUND

Since substitution of the tactile sense for other, impaired modalities is an increasingly common form of information encoding, it is important that devices presenting information tactually be maximally congruous with the processing capabilities of the tactile modality (2). Because of its speed and data-processing capability, the computer is a valuable aid to this research in sensory substitution.

STATEMENT OF THE PROBLEM & RATIONALE

The major obstacle encountered in interfacing an OPTACON with a computer is the development of a flexible "shell" from which software packages are constructed. Existing software interfaces were found to be too rigidly structured and application-specific. Since we needed to deliver stimuli in a number of qualitatively different ways, we found that we could not use existing software interfaces. While the OPTACON-computer interface system developed by (3) utilized a MicronEye camera to digitize images for later presentation, we wished to avoid the expense of any additional hardware. Stimulus patterns were generated in the software, precluding any additional expense, and also simplifying the (oft-repeated) task of manipulating tactile spatio-temporal stimulus patterns delivered to the tactile array of the OPTACON.

DESIGN

The system consists of an IBM PC XT microcomputer linked to an OPTACON via an interface circuit board installed in one of the computer's 8-bit expansion slots (see 3, for a more thorough description). Also included in the system are an OPTACON Visual Display unit and a user control unit housing five pushbuttons. All software packages were programmed in the C language and incorporated the basic OPTACON driver shell, which was written in 8088 assembly language for maximum speed of execution. This software shell handles interrupts from the OPTACON to ensure proper timing, and dumps data to the OPTACON using the required interlaced display mode.

DEVELOPMENT

The system described above was used to create software for a number of sensory-perceptual experiments. These programs were written and compiled using Borland's Turbo C 2.0, which allows for inline assembly language embedded in the C code (necessary to access the driver shell). Stimulus data were stored as a matrix of bits, which provided a convenient visual metaphor for the OPTACON display matrix. While representing the data this way takes more space in the source code, it also facilitates changes to any matrix. For easy manipulation of data within the programs, the bit matrix was handled as an array of (8-bit) bytes. A critical stimulation dimension was to ensure that the tactile matrix of the OPTACON could be used in either static or dynamic modes of stimulus presentation. The first method involves presenting symbols or patterns on the OPTACON's tactile matrix without modification for a certain length of time. For example, pilot studies investigating temporal integration and spatial resolution of the fingertip were carried out by presenting different sizes of gaps between pairs of stimulus "bars". The second method of presentation is dynamic display, in which characters or patterns are scrolled at different rates across the display matrix in so-called "Times Square" mode. (Note that if letters are scrolled right-to-left across the fingertip, the software can mimic tactile reading using the OPTACON.) Several studies examining differences in symbol discrimination as a function of presentation rate have been carried out using such diverse stimuli as horizontal and vertical bars, and "nonsense" symbols.

EVALUATION

While the software interface allows for the presentation of a wide variety of stimuli in a number of different ways, there still exist limits on what information can be tactually delivered to the fingertip. The OPTACON's vibrotactile matrix is limited to a minimum display time of about 4 ms (i.e., the period of one cycle of the device's pins, which vibrate at 230 Hz). No pattern presented for less than 4 ms can be reliably considered to have produced an indentation on the fingertip. Second, the area of the skin covered by the matrix is small (1.1 x 2.7 cm). As a result, there is a limitation on what stimuli can be presented: if a pattern is presented at too high a resolution, fine details produced by the OPTACON display will be imperceptable. This poor perception of high spatial frequencies on the fingertip is due to a physiological limitation. Rapidly adapting (RA) mechanoreceptors (Meissner's afferents) and Pacinian corpuscles (PCs) in the skin are strongly excited by spatial patterns presented on the OPTACON, due to its (relatively high) frequency of vibration. However, RA and PC receptors have poor spatial resolution compared to the slowly adapting (SA) afferents (4), which are not excited by the 230 Hz vibrations produced by the OPTACON (5). Thus, any patterns presented using the OPTACON must be coarse enough to fall into the comparatively large receptive fields of the RA and PC mechanoreceptors.

DISCUSSION

In addition to its primary use as a research tool, the modular software interface may be employed by OPTACON end-users. For example, a self-teaching software package could be developed for novice OPTACON users. Such a program would reduce the demands on OPTACON tutors, and may also speed up the learning process. Also, a software package could be developed that converts ASCII-format text to tactually-readable OPTACON output, allowing the blind access to the massive amount of information stored in computer databases. As discussed above, the interface between the OPTACON and microcomputer is an important research tool. The modular nature of the software interface facilitates the development of software packages for experiments in sensory substitution. And, as more information on tactile information processing is gathered, we may move closer to the goal of having tactually-presented stimuli maximally compatible with the processing capabilities of the tactile modality.

REFERENCES

1. Bliss, J. C., Katcher, M. H., Rogers, C. H., and Shepard, R. P. *Optical-to-tactile image conversion for the blind*. IEEE Trans. Man-Machine Systems, 11:58-65, 1970.

2. Bach-y-Rita, P. *Sensory substitution in rehabilitation*. Sensory World, 39:12-19, 1980.

3. Kaczmarek, K., Bach-y-Rita, P., Tompkins, W. J., & Webster, J. G. *A tactile vision-substitution system for the blind: Computer-controlled partial image sequencing*. IEEE Transactions on Biomedical Engineering, Vol. BME-32, No. 8:602-608, 1985.

4. Gardner, E. P., and Palmer, C. I. *Simulation of motion on the skin: I. Receptive fields and temporal frequency coding by cutaneous mechanoreceptors of OPTACON pulses delivered to the hand*. Journal of Physiology, 62(6):1410-1436, 1989.

5. National Research Council. *Sensory enhancement and substitution*. In Electronic Travel Aids: New Directions for Research (pp. 53-66). Washington, DC: National Academy Press, 1986.

Karsten A. Loepelmann
Department of Psychology
P220 Biological Sciences Building
University of Alberta
Edmonton, Alberta, CANADA
T6G 2E1

21.3

TOWARDS A METHOD FOR COMPUTER INTERFACE DESIGN USING SPEECH RECOGNITION

Cheryl Goodenough-Trepagnier* & Michael J. Rosen**

*Department of Rehabilitation Medicine
Tufts University School of Medicine
Boston, Massachusetts

**Department of Mechanical Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

ABSTRACT

An experimental project has begun in which the approach of abstract assessment, modeling and prediction of user-device performance is being applied to selection of computer interface designs for disabled users of computers. A novel aspect of the project is the application of this technique to speech recognition: the interface designs evaluated will combine speech input and standard and adapted input devices. The eventual objective of this project is an experimentally validated methodology to identify optimal interface designs for individuals with neuromotor disabilities, including dysarthria, who are performing specific computer-aided tasks.

BACKGROUND

Since speech recognition became a commercially feasible input option in the mid-1980's, there has been interest in utilizing this technology in the service of people with disabilities. Speech recognition has been shown to be a practical computer access mode for people with motor limitation or disability that spares speech, and has been successfully used in vocational settings for individuals with this type of disability (e.g., 3). The technology itself is sophisticated and powerful. It is usable, via appropriate interface designs, by technically naive users, and enables them to perform tasks ranging from medical reporting to operation of a robotic manipulator for environmental control.

Unhappily many individuals with disabilities affecting the upper limbs also have speech impairment, ranging from mild dysarthria to speech which is not functional in most contexts. Dysarthria, the general term for neuromotor impairment of speech, varies with the etiology of the disease process or injury, the location of the lesions, and the severity of the condition in terms of extent of damaged tissue or stage of recovery or degeneration. Articulation is a highly complex, precisely orchestrated motor activity. Slight deviations in position of the articulators, or timing of the articulatory movements, as a result of breakdown in neuromotor control, may result in the listener's being unable to map the intended message onto the acoustic material. Variability of articulation and low signal-to-noise ratio may also interfere with effective message transmission.

It must be noted that conversational partners have a lot more than just the acoustic signal to go on. They usually have some knowledge about the speaker. Typically conversational partners share the same context, including some or all of location, situation and topic. In addition, the receiver brings to bear a body of social knowledge, expectations and pragmatics which support his language processing. In contrast, the speech recognition machine utilizes the speaker's acoustic production and its own set of acoustic processing rules to attempt to identify which of the pre-trained vocabulary items is the best match to the speaker's present utterance.

There have been reports of trials of automated recognition of dysarthric speech using one or two participants (e.g., 1), and grouped data from a larger number of participants and control participants who were not dysarthric (4). Review of these studies suggests that speech recognition performance rapidly deteriorates for vocabulary sizes greater than approximately 30 words, despite the fact that the participants have typically been individuals with mild to moderate dysarthria. It is evident that individuals whose dysarthria is severe enough that they may derive benefit from using augmentative communication devices in some contexts cannot be expected to have much to gain from speech recognition used in this manner. Accordingly, some investigators (e.g., 4) have recommended further software and hardware development to improve the performance of speech recognition machines with people whose speech is dysarthric.

The studies referred to above of the utility of speech recognition for people with dysarthria have had in common the assumption that, in order to output a large vocabulary of words or commands or functions, the speaker must input that vocabulary. The project described here utilizes a different approach to automatic recognition of dysarthric speech. The long-term goal is the improvement of the individual's ease and efficacy of computer operation, in order to improve job productivity. The approach adopted in regard to speech is to treat the speech of the individual with dysarthria as an additional domain of potential control signals, analogous to the motor acts that s/he can produce to control typical input devices. Viewed from this perspective, the reports of reliable recognition of 30-word vocabularies may be interpreted more positively. If an arbitrarily selected 30-item vocabulary can be reliably recognized, presumably a custom input vocabulary, selected according to how its articulatory characteristics suit that individual's speech and according to recognition accuracy, can be expected to result in improved performance. It may be that, even for individuals with severe dysarthria, a small set of utterances can be selected, based on their articulatory and acoustic, not semantic, properties, which will elicit reliable recognition.

STATEMENT OF THE PROBLEM

Some individuals with severe neuromotor disability affecting control of limbs may presently access computers using standard and alternative interfaces, but performance is typically dramatically impaired relative to individuals without disability who utilize standard interfaces. To improve productivity of computer users with neuromotor disabilities, interface selection and design must be based on three steps: objective assessment, user modeling from assessment results, and performance prediction from the user model.

APPROACH

As suggested above, the approach taken in this project is to treat speech capacity, like the rest of the individual's residual motor ability, as a potential reservoir of control acts which may be optimally mapped to the control of a device, such as a computer, in order to produce desired outcomes. This approach is an extension of the one taken in the development of the Tufts-MIT Prescription Guide (2 & 5). An analogy may be drawn to the treatment of manual control of devices by individuals with motor disability. Rather than require typical nine-finger operation of standard keyboards, or perhaps designing "smart" keyboards which can sense the intended finger movement by filtering out the involuntary tremor and ataxia, an **alternative** input device may be selected. Despite the evident advantages of typing, at least for people without movement disabilities who have acquired this skill, it may well be that for a particular individual, use of a very different interface (e.g., an expanded keyboard, even a single-switch scanning device) may turn out to be more effective. The question is an empirical one, and is best dealt with by identifying the essential components of the operation of each interface in question, and conducting an assessment of the individual's performance as the values of those parameters are sampled through the range which can be encountered in actual devices. In the case of speech, rather than requiring that the individual articulate the words of the output message or command, in an adequately reliable manner to assure high recognition accuracy, the approach adopted in this project is to determine how to utilize residual speech capacity, with a speech recognizer, in combination with other inputs, to improve the output performance of the individual as s/he carries out the target tasks which are part of his/her job.
The initial task of the project, currently in progress, is to develop a heuristic and an evaluation procedure for identifying optimal sets of "speech acts". The goal is to specify the phonological characteristics of the most successful input vocabulary for a range of set sizes and accuracy levels (frequency with which the machine recognizes correctly on the first try). While the outcome is expected to differ across participants, it is anticipated that particular strategies will be useful to classes of participants (e.g., for dysarthria with a low signal-to-noise ratio, manipulation of suprasegmental features such as duration, pitch and volume may improve recognition scores).

An additional objective of the first phase of the study is to examine the relationship between the size, recognition score and phonological characteristics of selected vocabulary sets; and descriptors of the type of dysarthria, expressed as scores on standardized clinical dysarthria assessments.

Later phases of this study will integrate the speech assessment into an assessment of the individual's whole repertoire of potential control techniques. Data from this assessment will be analyzed to model the user's performance in order to calculate and compare benchmark scores for competing interface designs. Such models, which could take the form of look-up tables or of closed-form equations, serve to represent the relationship between the individual's performance and the crucial physical parameters of interfaces. The model stands in for the user as each potential interface design is evaluated by calculating the performance that the interface will enable the user to achieve.

IMPLICATIONS

One of the implications of this approach is that it requires analysis of the computing tasks the individual will be performing. In studies of augmentative communication (5), a large, representative sample of messages produced by several users of augmentative devices served as a benchmark task. Predictions of user-device performance in producing that language sample were found to be highly correlated with experienced users' actual communication performance. Computing tasks representative of those which disabled computer users can expect to perform as part of their job activity will need to be identified. These will serve as the basis of performance predictions for new interface designs, which will utilize speech and other inputs, to be developed in the course of this project.

DISCUSSION

For individuals whose upper limb control is limited in range, strength or accuracy, utilization of automatic speech recognition offers additional control acts among which the operation of a computer application may be shared. One anticipated outcome of this will be an improvement in rate of performance of the individual's job tasks. Equally, if not more important, is another anticipated result, an interface which is comfortable, appealing and easy to use, and enhances the individual's feeling of control and expertise in the performance of his/her job.

Acknowledgments

Funding for this project is provided by the Department of Education under the Demonstration and Innovation Projects of National Significance Program in Technology-Related Assistance for Individuals with Disabilities.

The authors gratefully acknowledge David Horowitz's contribution of his speech recognition expertise to the development of this approach.

REFERENCES

1. Ahmed, W.W. (1985). Computer recognition of cerebral palsy speech. Proceedings of the Speech Tech '85 Conference. New York: Media Dimensions, Inc.
2. Goodenough-Trepagnier, C. & M.J. Rosen. (1988). Predictive assessment for communication aid prescription: Motor-determined maximum communication rate. in L.E. Bernstein, Ed. The Vocally Impaired: Vol. II - Basic research and technology. Philadelphia: Grune & Stratton. 167-185.
3. Hausdorff, J. & Horowitz, D. (1990). Preliminary evaluation of a voice-controlled robotic work station. Proceedings of RESNA 13th Annual Conference. 125-126.
4. Rodman, R.D. (1989). Computer speech recognition in augmentative communication. Journal of the American Voice I/O Society. 6. 61-75.
5. Rosen, M.J. & Goodenough-Trepagnier, C. (1989). The Tufts-MIT Prescription Guide: Assessment of users to predict the suitability of augmentative communication devices. Assistive Technology. 1(3), 51-61.

Cheryl Goodenough-Trepagnier
Tufts University School of Medicine
750 Washington Street, 75 K/R
Boston MA 02111

BEST COPY AVAILABLE

21.4

A User's Perspective on Blind Access to Graphical User Interfaces

Kelly Ford
Trace R&D Center
University of Wisconsin-Madison

Abstract

With computers such as the Apple Macintosh and operating systems such as Microsoft Windows becoming more and more commonplace in the microcomputer world, it is apparent that the Graphical User Interface (GUI) access approach to computing and the bit-mapped screen will soon become standard. For this reason, it is vital that strategies as well as actual solutions to the problem of providing access for persons who are blind to computers utilizing a GUI approach be developed. This paper will examine Systems 3, one such solution, from the perspective of a blind user. This paper is intended to provide an overview of the Systems 3 project as well as to stimulate further discussions on the topic of providing access for persons who are blind to GUIs.

Background

The Systems 3 project's primary goal is to develop an access system to graphics-based computers for persons who are blind – with current work being done using the Apple Macintosh as the development platform. A prototype of a multisensory, multiaccess system has been developed and is being tested to determine future work for the project.

Statement of the Problem

While it has long been possible for computer users who are blind to access the textual information and programs running on character-based computers such as the IBM PC, the introduction of graphics-based systems like the Apple Macintosh and Windows 3.0 has allowed both the type of information displayed and the programs run on computers to change dramatically. This means that an effective access system for persons who are blind must not only allow access to the new type of information being produced by these computers, but also to the GUI approach to computing in general. Additionally, computer users who are blind must be introduced to the GUI with an access system that affords them the opportunity to take full advantage of this type of interface. Computer independence, which has been possible for years in the character-based environment, must be maintained and expanded upon with any access system developed for the GUI.

Approach

System Components and Operation

The current Systems 3 prototype consists of a modified and extended version of outSPOKEN, a commercial program that provides keyboard access to text, iconic images dialog boxes and menu bars; a graphics tablet; and a mouse-like puck with a vibrotactile array built into it. A plastic overlay fitted to the graphics tablet allows the puck to be moved with an absolute reference relationship to the screen. As the puck is moved around the tablet, a tactile image of the screen region surrounding the mouse pointer is displayed on the vibrotactile array for interpretation by the user. The effect is that the user can feel the image on the screen as they move the tactile mouse/puck around on the tablet. In addition, several rows of dimples on the tablet's edges provide quick access to standard computer functions such as the Menu Bar. The system uses Macintalk which provides speech synthesis functions using the built-in sound capabilities of the Macintosh.

How the System Works

Due to the multisensory, multiaccess nature of Systems 3, several access techniques may be used to explore application software and files. In general, the puck, with its tactile array, is moved around the tablet when a file is first opened. This provides immediate feedback on the type of file and format of information the file contains; e.g., a three-column word processing file or a multi-column spreadsheet. As the user moves the puck around the tablet, the mouse pointer moves accordingly, and any text that is encountered will be verbalized. Symbols or icons touched by the mouse pointer will be announced as "Symbol" and "Icon," respectively. With a keyboard command, the user can then attach a text definition to these items that will be spoken any time the symbol or icon is encountered – "Open Folder Selected," for example.

For reading of information that is not highly formatted – columns with standard margins and no graphical information – key combinations may be used to read a character, word, line or screen at a time. A keyboard command also allows scrolling to a precise percentage up, down, right or left within a file. The user may also manually scroll the file by using the puck to locate and "drag" the "elevator" on the scroll bar in the desired direction. Additional keyboard commands allow the user to do a scrolling search for any on-screen text, including previously defined iconic images; determine the font, point size and characteristics of text, attach a placemarker to a screen location; and locate and go to the Insertion Bar, if one is present.

Manipulation of the Menu Bar may be done by either pressing a key and then stepping through selections with additional key presses, or by using two rows of tablet dimples set aside for this purpose. If the keyboard approach is taken, access to menu selections can be made faster by typing letters from the alphabet once the "Menu" key is pressed. If the user opts to use the tablet dimples to make menu selections, the puck is moved to a row of dimples where the Menu Bar is accessible. "Clicking" in a dimple with a Menu Bar title causes that menu's choices to be placed in another row of dimples on the tablet. The user may then select from these choices.

For movement between windows, the user again has a multitude of options. First, a keyboard command may be used to enter a menu of all open windows from which the user may then select. Second, the desired window may be chosen from a list of open windows always available in one row of dimples on the tablet surface. Finally, the user may directly select any window in the standard Macintosh fashion – by moving to and "clicking" in the desired window. Window resizing can be accomplished with either a keyboard command or by manually dragging the resize box.

Why Tactile Feedback?

While accessing textual information is a fairly straightforward process that can be accomplished with auditory feedback exclusively, the Macintosh makes it easy for all users to create documents that utilize graphical information as well. Bar charts, line drawings and pictures are just some examples of this type of information. The tactile feedback technique used in Systems 3 makes it easy for the user to explore and understand this information. If, for example, a bar chart is to be examined, the user can quickly determine the relative lengths of the bars in the chart with a few sweeping motions of the puck. Then, a more detailed examination can be performed by moving to the endpoints of each bar individually. Any labels attached to the bars will be automatically verbalized when they are touched by the pointer. This same strategy can be used to examine other types of graphical information presented on the computer screen.

Implications

Recent trends in the microcomputer world make it obvious that the GUI approach to computing will eventually become standard. For this reason alone, persons who are blind must have access to this type of computing environment. The goal of the Systems 3 R&D project is to meet that challenge and provide computer users who are blind the same level of functionality as their sighted counterparts. If the project is successful, a commercially available access system will be available for the Apple Macintosh in the short term, and a platform-independent access system in the long term. Furthermore, the project team hopes to create tools that may be used by other developers wishing to entire the field.

Discussion

Impressions

A good computer access system should not only be functional, but also easy to use. It should allow the computer user to take full advantage of whatever benefits the computer being accessed has to offer. Application software should not be selected because it "works" with the access system. Instead, the user should be able to choose software based on its performance capabilities – with access system compatibility not being an issue. It is therefore important to examine Systems 3 based on its ability to allow the user to use the Macintosh.

The Macintosh, with its GUI approach to computing, requires far less knowledge to operate at the system level than any character-based system. Dragging files to new folders or clicking on a file to open it is much easier to learn than the commands necessary to accomplish these tasks in the DOS environment. However, for the blind user familiar with a character-based system's command line approach to task completion, the Macintosh approach will most likely seem slower at first. But, if a macro program is used to automate routine functions such as opening an application or making a menu selection, accomplishing an equivalent task becomes faster on the Macintosh.

Within applications, there is no question that Macintosh users have a number of tools at their disposal. Standardization of software control functions required by the operating environment is a major benefit to computer users in general and more specifically those who happen to be blind. For the user who is blind, perhaps the most difficult challenge is figuring out ***when***, not ***how***, to use each tool. Should titles be in 10 or 12 point size? What character should be used to mark items in a list? These are just two examples of questions that must be resolved by the computer user who is blind. They are, however, questions which deal with presentation of information based on visual appearance.

The combination of haptic, tactile and auditory feedback used in Systems 3 is a major step in the direction of allowing this type of information to be understood by computer users who are blind. It is much easier to understand what "bullets" are and how they are used when you can feel a list that uses them, rather than just having a speech synthesizer say "bullet."

For reading text, there is no doubt that auditory feedback is the most effective access method. However, there are benefits to having the ability for tactile feedback as well. Fonts become more than just words. In fact, Systems 3 can display individual characters on the tactile array, permitting the distinctions between fonts to be felt.

The multisensory, multiaccess nature of Systems 3 allows the computer user who is blind to take full advantage of the Macintosh's GUI. For example, when working with spreadsheets on a character-based system, it is often necessary to count the characters to be placed in each column in one's head and then adjust margins accordingly. In contrast, the same task can be performed on the Macintosh by simply moving to and clicking in the appropriate cell with the tactile mouse/puck. Text may then be entered and margins adjusted based on how the page feels.

In addition to providing access to the same type of information currently available in character-based documents, Systems 3 allows access to documents and information that can only be displayed effectively in a graphical format. Maps, line art and floor plans are just a few examples of the type of graphical information that can be easily accessed. This simply isn't possible with a speech synthesizer alone. Systems 3 also allows one to do things like drawing, which also cannot be explored at all with character-based computer access systems.

In addition to allowing access to graphical information, the capability of tactile feedback allows the GUI interface to be more easily understood by the computer user who is blind. Scroll Bars, Windows and Pulldown Menus become more than words when they can be felt and manipulated. The often highly formatted and confusing Dialog Boxes can be explored in detail.

Although Systems 3 is highly functional, it is not without shortcomings. First, because the tactile array uses vibrotactile technology, it tends to be noisier than is desirable. Second, despite the fact that icons can be felt and verbalized as "icon," it is sometimes difficult to know what the icon represents in order to assign it a text definition. Finally, complex graphical and photographic images are still nearly impossible to interpret.

Future Issues to be Addressed

Systems 3 is a project that is still in the development phase. As such, significant issues remain to be solved. Access to complex graphical information such as computer animation must still be attained. In additional, rapid and selective access to Dialog Boxes is something that requires further study. The use of tones, crosshairs and stereo sound imaging to assist in navigation is just beginning to be explored. The use of voice control to navigate will also be examined. Nevertheless, the multisensory, multiaccess approach to accessing GUIs appears headed in the right direction. Just as the Apple Macintosh allows sighted users to have easier access to the computer and do more with the machine, Systems 3 allows the computer user who is blind to have access to this new computing environment.

Acknowledgements

Systems 3 is a cooperative research and development project being carried out by the Trace Research Center (TRC) of Madison, Wisconsin and Berkeley Systems, Inc. (BSI) of Berkeley, California. Support for the Systems 3 project has been provided in part by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education (Grant #H133E80021); Apple Computers, Inc.; Telesensory Systems, Inc.; and Articulate Systems, Inc.

Kelly Ford
Trace R&D Center
S-151 Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280

HARDWARE DESCRIPTION OF A PORTABLE ELECTRONIC MEMORY DEVICE

Mark Friedman[1], John Kostraba[2], Kimberly Henry[1], John Coltellaro[1]
[1]The Rehabilitation Institute of Pittsburgh, Pittsburgh, PA
[2]Kostraba Engineering Associates, Denver, CO

ABSTRACT

A preliminary study in the use of a portable electronic device as a memory aid for persons with cognitive disabilities has been completed. The research protocol used for this investigation is described in an earlier paper (1).

The development of prototype test units, which provide spoken messages at pre-determined times throughout the day, was an important component of this project. This paper outlines the motivation for developing a portable, interactive electronic memory aid as well as the hardware design.

BACKGROUND

Various approaches have been developed to provide individuals with cognitive disabilities with cues to assist them in independently following a daily schedule. A written schedule or log book where the day's events are recorded is the most common example (2). An obvious extension of this approach is to add a timed alarm (a watch or timer) to serve as a reminder for the individual to check his or her schedule or log book for specific information (3). This process, however, depends upon the performance of several cognitive activities including attending to the beeping watch, remembering what the beeping means and using that cue to initiate the proper action. Unfortunately, there are many patients who are not able to benefit from this type of assistance due to the limitations in initiation, planning and memory skills. Studies have confirmed the limitations of conventional approaches (4).

A growing number of pocket-sized electronic devices that act as appointment schedulers, calenders and notepads are becoming available on the market. These off-the-shelf electronic organizers, however, have features which make them unsuitable for many patients. First, devices with multiple modes of operation are often confusing for these individuals. Second, some units require the user to selectively view information that has been stored. Those patients with cognitive disabilities who lack initiation and planning skills will never actively retrieve the messages stored in the device. Finally, cues displayed in only a single format, namely as printed messages, are not always the most effective. Some patients process and respond better to auditory information, in particular, spoken messages. J.E. Harris outlines specifications for a portable memory aid that is a dedicated, single function device which uses a combination of visual feedback and recorded speech to provide prompts at pre-set times (5). Although a working device based upon these specifications was never fabricated, the concepts emphasized in the description are fundamental to the design of a practical memory aid.

DESIGN CRITERIA

After consultation with CRT (Cognitive Retraining Therapy) clinical staff who are responsible for our head injury program, we developed specifications for a wearable electronic memory aid to assist their therapeutic effort. There were half a dozen basic requirements for the prototype device:

1. The unit should have a time activated transient visual display that is easy to read.

2. The unit should have high quality speech output to complement the written messages and audio tone outputs to alert the user to attend to the messages.

3. The unit should provide an option for encoding the recognizable speech of specific people (including the device user, the user's family members, or clinicians) to enhance the effectiveness of spoken messages. This stored vocabulary should be large enough to allow a variety of short messages to be composed from prerecorded segments. The encoded speech must be easy to edit, store, and reconfigure.

4. The unit should have a means by which the user can respond to acknowledge device-generated messages.

5. The unit should have a means for confirming the time that scheduled activities have been completed. This should be independent of other device functions so that clinical effectiveness and possible placebo effects can be evaluated.

6. The unit should be comfortably wearable. As a design goal we desire a size comparable to commercial "walkman"-style, personal, wearable audio entertainment devices.

PROTOTYPE IMPLEMENTATION

Device functions were segmented onto three identically sized, stackable custom printed circuit boards: a memory board, an interface board, and a microprocessor board.

The memory board stores alpha-numeric character strings that are used as messages for the device user. It stores the digitized speech that corresponds to the alpha-numeric messages, and it stores user response time and task completion time data. It is populated with address demultiplexing hardware and eight bank-selected 32 kilobyte low-power static memory chips.

The interface board has audio amplifiers and a monolithic 'codec" to encode speech input from a microphone jack into a serial digital bit stream. Under microprocessor control, the codec can decode a digital representation of speech back into speech waveforms. It can power a high impedance earphone or binaural headset through an onboard miniature impedance-matching transformer. To reduce digitization noise at low-bit rates, the codec has on-chip switched capacitor anti-aliasing filters. In addition to audio I/O, the interface board provides circuitry to buffer 4 switch inputs and to control a board-mounted 2-line x 6-character alpha-numeric LCD display. In some experimental paradigms, a user pushes one of the switches to acknowledge device-generated messages, while another can only be activated magnetically by a teacher or therapist when the user arrives at his or her destination.

The microprocessor board is built around Motorola's 68HC11 CMOS 8-bit processor. Its non-volatile program resides in 16 kilobytes of external EPROM. The 68HC11 controls all device activity, including patient alerting and response timing, speech I/O, and host computer interface. Digital representations of speech waveforms are buffered in 16K bytes of CMOS RAM on the microprocessor board while waiting for transfer to the memory board or the codec. Bit-serial data transfer to the codec is made via the 68HC11's synchronous serial port. ASCII communication with a PC-host computer is via the 68HC11's asynchronous serial port. This host is used to download daily schedule information and speech information to the portable reminder each morning and to record the user's response times at the end of the day.

The electronics, including rechargeable batteries which are to be charged each night and a display for the portable reminder, fit in a 3 inch x 2 inch x 6 inch plastic case that is belt worn.

Recent advancements in integrated circuit technology which would improve the performance of these test devices are being incorporated into a second phase design. Technology capable of enhancing digitization of recorded speech as well as other relevant functions performed by these test units will be discussed.

ACKNOWLEDGMENTS

The authors gratefully acknowledge The Buhl Foundation for their support of this project.

REFERENCES

1. Henry, K., Friedman, M., Szekeres, S., Stemmler, D. (1989) "Clinical Evaluation of a Prototype Portable Electronic Memory Aid." RESNA '89: Proceedings of the 12th Annual Conference, pgs. 254, 255.

2. Malkmus, D., Booth, B. J., and Kodimer, C. (1980) Rehabilitation of the Head Injured Adult: Comprehensive Cognitive Management. Ranchos Los Amigos Hospital, Inc., pg. 34.

3. Harris, J. E. (1978) External memory aids. In Graneberg, M. M., Morris, P, and Sykes, R. (Ed.) Practical Aspects of Memory. New York: Academic Press.

4. Kirsch, N. L., Levine, S. P., Lajiness, R., Mossaro, M., Schneider, M., and Donders, J. "Improving Functional Performance with Computerized Task Guidance Systems." Proceedings of the International Conference of the Association for the Advancement of Rehabilitation Technology, pgs. 564-567, 1988.

5. Harris, J. (1984) Methods of Improving Memory. In B.A. Wilson and N. Moffat (ed.), Clinical Management of Memory Problems. Aspen Publication, pgs. 46-62.

Kimberly A. Henry
Rehabilitation Engineering Dept.
The Rehabilitation Institute of Pittsburgh
6301 Northumberland St.
Pittsburgh, PA 15217

Prospects of Automatic Speech Recognition and Relay Service

D. Kanevsky, C. Danis, G. Daggett, E. Epstein, P. Gopalakrishnan, D. Nahamoo
IBM Research Division, T.J. Watson Research Center, P.O Box 704,
Yorktown Heights, N.Y., 10598

Abstract

This paper presents an optimistic outlook on the possibility of developing of phone communication aids based on an automatic speech recognizer (ASR). A new, more efficient set up for using a Relay Service Center (RSC) that was initiated by a few hearing impaired IBMers is described. Psychological and social issues affecting use of an ASR or a RSC and their interrelations are discussed.

1. Introduction

The main objective of the paper is to direct the attention of people working in the hearing impaired field to the possibilities of using current speech recognition technology to design communication aids. Some in this research community have been rather skeptical about the prospects of using an ASR for this purpose in the near future (see for e.g. [3], pp.4 and 20) and underestimate the number of the hearing impaired who need qualified transcription services. We present in this paper some data and observations challenging this notion and indicating that an ASR could play a significant role as a communication aid for the hearing impaired community.

There are nearly 22 million hearing impaired persons in the USA who have difficulty understanding speech. The means that the hearing impaired would chose to perform phone conversations depends on the level of their hearing loss and intelligibility of their speech. The traditional point of view is that the only options for the profoundly hearing impaired (numbering about two million) are TDD (Telephone Device for Deaf) or Relay Service Centers. The rest of the hearing impaired are expected to use hearing aids in order to perform phone conversations.

Phone communication for the hearing impaired is a very natural application for an automatic speech recognizer (ASR). ASR can be used to decode the sentences spoken by a user (over the phone) and print decoded sentences for viewing by a second user. We recall briefly some successful experiments reported in [1, 2] on the application of an ASR (named "Tangora") that was developed by the speech recognition group at the IBM T.J. Watson Research Center (TJWRC). We describe the technical and psychological issues that arose in these experiments. There are a lot of similarities between performing phone conversations with the help of an ASR and a relay service operator. The comparison of these two different schemes is useful and gives hints on how to organize future phone services that could be based on the use of both automatic and human interpreters. This topic is covered in the final part of our paper.

2. Studies with a Speech Recognizer

Tangora is an isolated word, speaker dependent automatic speech recognition system operating on a vocabulary of 20,000 words. Though the system performs best with a close-talking microphone (giving an average accuracy of 95% for sentences drawn from the 20,000 word vocabulary), it can be used to recognize speech over a telephone line, with some deterioration in accuracy resulting from reduced bandwidth and line noise. In order to study the usefulness of the recognition system under such conditions we performed telephone experiments with 12 hearing and profoundly hearing impaired subjects who used the ASR to help them communicate by telephone with hearing individuals. If the hearing impaired had intelligible speech they responded over the telephone by voice; otherwise they typed their responses, which was displayed on the terminal of the hearing individual. Hearing individuals and hearing impaired users who participated in the experiments were sometimes located at various remote cities as Chicago, Fishkill, Princeton etc. In all these experiments the Tangora was located at TJWRC. Decoding accuracy in these experiments varied between 75% and 98% for different speakers. It became quite clear from these experiments that the hearing impaired are able to achieve very good comprehension when the topic of conversation was more or less clear. Hearing individuals reported the impression of an "almost normal" phone conversation.

3. A few observations from the telephone experiments

This section summarizes some useful observations resulting from experiments described in the previous section.

A) The hearing impaired and profoundly hearing impaired found phone conversations useful even in the case of comparatively low decoding accuracy (on the level of 80%). In most cases they were able to reconstruct the meaning of spoken sentences from the incorrect ASR output using the context, acoustic similarities or using knowledge of typical errors made by the ASR (see [2] for a more detailed analysis). Their skill and speed in understanding inaccurate ASR output significantly improved with practice. At the end of prolonged usage the hearing impaired users reported that they read inaccurate ASR output as 'easily' as correct text.

B) Two hearing impaired who normally use hearing devices to speak over the phone still found the Tangora helpful as a phone aid. These users reported that when carrying out phone conversations with the help of hearing aids alone they often concentrate so much to understand the words that they were not able to keep track of the sentence. This problem was immediately resolved when they started to use the Tangora since decoded sentences were displayed on a terminal and users could verify was what said.

C) Hearing impaired individuals indicated that the majority of the time they need to perform phone conversations with their family members or close friends rather than with strangers. Family members and close friends usually expressed readiness to spend some time to train the Tangora. This shows that perhaps the suitability of a speaker dependent ASR to help in phone conversations was not fully appreciated by experts in the hearing impaired field.

4. The relay service set up

The hearing impaired can attempt to communicate over the telephone using a Relay Service. Generally these conversations are performed as follows. The hearing impaired person calls a relay service operator and communicates with him/her via a modem line using a TDD device. In this setup, both the hearing impaired and a relay service operator communicate by typing their messages. The relay service operator calls a hearing person with whom this hearing impaired person wants to speak. In this conversation the hearing impaired types out messages to the relay service operator, the relay service operator repeats these messages to the hearing person by voice, who, in turn, answers by voice to the relay service operator. These answers are typed back to the hearing impaired.

Some of the relay service centers have a Voice Carry Over (VCO) provision that provides an opportunity for the hearing impaired to use their own voice in phone conversations. Even with this option, the services are slow and inefficient and many hearing impaired people are reluctant to use them. However, the following scheme may be more attractive for hearing impaired users. First, the hearing impaired person establishes a link with a relay service operator in a such way that he/she can read what the operator types to him/her and communicate messages to the operator by his/her own voice. Such a link can be established by using two phone lines (one for characters and another for voice data). This gives an opportunity for the hearing impaired user to start to speak even before the operator finishes typing his message. (In principle, using special methods like time or frequency multiplexing that allow both types of data through the same line, one can have the same type of communication with one phone line). Next, the hearing impaired person calls another (hearing) person and when somebody picks up a phone on the other end, the hearing impaired links the relay service operator with the third party using conference call features. In this the step the hearing impaired can use a hearing or tactile device, since in the current conference setup (the so called three-way call) the operator can be connected to the third party only after the hearing impaired user knows that the third party has picked up the phone.

In addition when using two lines (or a special multiplex line) with the operator and a third line with the conversational partner, a tactile or hearing device allows the hearing impaired to determine when the third party has finished speaking and to start to answer without waiting for the operator to finish typing. In practice, we find that when a large part of a spoken phrase has been typed, the hearing impaired user can start to say something since he can guess the remaining part of the phrase from the context. This saves a significant amount of time and thus makes conversations cheaper (especially for long distance calls) as well as being psychologically more comfortable for the hearing user. Such control of the conversation with hearing and tactile devices was impossible in the old relay service setup where everything is controlled by an operator. In several instances using this new scheme, the hearing persons did not even realize that they had just had a conversation with a profoundly hearing impaired person.

It is interesting to note that for some hearing impaired individuals using this scheme, the number of calls made by them increased twofold once they started to use this scheme. One can expect that when this becomes known to more hearing impaired persons the number of people willing to use the relay service and the number of calls will sharply increase. It is necessary to find out the actual number of people who need the improved variant of the relay service and estimate the number of calls that they will make.

5. Comparative characteristics of ASR and RCS.

Some of the advantages of the improved relay service method in comparison with an ASR based service are the following: 1) The relay service operator can operate with continuous speech 2) It does not requires the hearing user to go through a training procedure as in the case of a speaker dependent ASR. 3) The accuracy of the output produced by an operator is higher than one can expect from ASRs in the near future.

The main disadvantages in the use of a relay service vs an ASR are the following. 1) The relay service involves a third party in the conversation, providing no privacy. 2) The use of operators is very expensive. One can expect that eventually an ASR that is shared by many users will be less costly than the relay service centers. 3) If the efficient setup of the relay service will be actually implemented for wide use and more hearing impaired users will be interested in it, one can expect that there will not be enough operators to perform all the required calls. One alternative is to use an ASR to help the relay service operator.

We conclude this section with some remark on how future relay services that are based on human and automatic interpreters could be organized. A relay service operator after receiving a call from a hearing individual checks whether he/she has already trained a speaker dependent ASR that is available at the new relay service center. If the answer is yes, the operator simply activates the corresponding module in the ASR and lets the ASR interpret the rest of the conversation. Otherwise the operator performs the call, simultaneously training the ASR on the new speaker since everything that this speaker says is transcribed and the ASR receives both acoustic data and the script that was used to produce this data. This is sufficient condition for training the ASR!

6. Conclusion

In this paper we outlined some factors that make the application of an ASR as a phone communication aid possible. The main factor is that current speaker dependent isolated speech systems (in particular the Tangora) achieve an accuracy of about 80% for telephone quality speech. This appears to be sufficient for people to satisfactorily comprehend the transcription made by the ASR. Under existing conditions ASRs can be used for conversations with people who would be willing to train the ASR - such as family members, friends, and other people with whom hearing impaired users routinely communicate. We also described a more efficient setup for the relay service. It appears from the analysis of experiments on phone conversations with help of the ASR and improved relay service that the number of hearing impaired persons who need these services is far larger than would be initially expected. The problem of providing a large number of hearing impaired users with a more effective relay service can be resolved by adding ASR features to these centers. We hope that this paper will also stimulate further work in this direction by others involved in this area of research.

Acknowledgement We are grateful to Tim Walls for some ideas on using the improved schemes for the relay service.

References:

1. D. Kanevsky, C.M. Danis, G. Daggett, P.S. Gopalakrishnan, R.T. Hodgson, D. Jameson, D. Nahamoo, "A Communication Aid for the Hearing Impaired Based on an Automatic Speech Recognizer", V European Signal Processing Conference EUSIPCO 90.

2. D. Kanevsky, P.S. Gopalakrishnan, G. Daggett, D. Nahamoo, "Using Automatic Speech Recognizer as a Phone Aid for Hearing Impaired", Adaptive Control and Signal Processing, IASTED 90, pp.101-104, Proc. of Conf. in New York, Oct. 10-12, 1990.

3. R.I. Damper, Speech Aids for the Handicapped, VSSP Group Technical Report 89/TR5.

D. Kanevsky, IBM Research Division, T.J. Watson Research Center, P.O.Box 704, Yorktown Heights, N.Y., 10598

21.7

SOFTWARE DESIGN GUIDELINES FOR ACCESSIBILITY TO A COMPUTERIZED CASE MANAGEMENT SYSTEM FOR SPEECH BASED SCREEN REVIEW SYSTEMS USED BY PEOPLE WITH BLINDNESS

Jon Gunderson, MS
University of Wisconsin at Madison
Department of Industrial Engineering
Madison, Wisconsin USA

Introduction

The layout and design of computer screens with the associated keyboard commands for interacting with the computer can have a tremendous impact on the usability of a software programs by people who use speech based screen review programs. This paper describes the design principles and guidelines used for the redesign of a computerized client management system for use with screen review programs. The original system was designed to be used primarily by sighted individuals who use a terminal emulation program on a MS-DOS compatible computer. Many of the recommendations to improve usability by people using screen review programs will also improve the usability for people using the visual interface. A Screen review program (SRP) provides the means for the user to direct the "reading" of different portions of the screen. The "reading" is accomplished by redirecting the information on that portion of the screen to an electronic speech synthesizer.

Case Management Task

The computerized case management system is used to process client information from the time of a clients application for services to the closure of their case. This includes changing and maintaining client status, demographic, financial and address information. The basis for the original screen design for the computerized case management system was the format of the printed forms which the case managers currently use. The original forms contain many numerical codes which are used to represent different characteristics of the client. The computerized system needs to allow the blind user a means to identify the appropriate codes and match them with the question they are answering. The user must also be able to easily select among the different functions available in the system. The system has several functions to track and maintain the client from their application to closure. The system needs to present this functional information in a way that the user can identify the options and determine how to use the options to complete their task.

User Profile

The users (both sighted and blind) of the management system are case managers most with little previous exposure to computers. The managers will only be using the system occasionally for short periods of time and many days not accessing the system at all. The occasional use of the system places greater demands on the user interface design to allow the managers to easily understand how to use the case management system to complete their job related tasks (Potosnak, 1987). In this situation the managers task performance time, in terms of number of keystrokes needed to complete the task, can be traded off for making more screens which are less cluttered with information. The simpler screens allows the addition of contextual information to the screen, which can be used to help the user to understand the options and actions associated with the screen.

The occasional user can be contrasted with a job which the users are almost always using the computer system, like a travel reservationist. In this situation the task performance time is very critical, since the time they take determines the number of customers they can serve, and how satisfied their customer will be. The travel reservationist therefore needs to become quite skilled in using the system and would demand more travel information be placed on the screen. Their skill and familiarity of using the system allows the reservationist to quickly direct their attention to information which will help them in assisting their customer. Though, through the eye of a naive observer the screen though may be quite uninteruptable.

Different users therefore require different designs, based on their background and the demands of the tasks they are performing. The redesign therefore must keep in mind that the case managers will only be using the management system occasionally and that they have little previous knowledge about computers.

Design Principles

The following is a list of seven design principles for use with screen review programs (SRP) accessing screen based software. These guidelines are adapted from Schneiderman (1987)

1. Consistency: Consistency in both keyboard commands and the layout of information is very important. Since the managers will also be using WordPerfect as a wordprocessor it would be consistent to use many of the same function key associations assigned by WordPerfect to similar functions and selection techniques within the case management program. The layout of the screen also needs to be very consistent with areas designated for certain types of information. This allows the manager with blindness to issue consistent SRP commands to identify and repeat the screen title, prompt, options, messages and errors that are presented on the screen.

2. Timely prompting of information: The timely presentation of information is very important in speech based SRP. The manager needs to have information automatically presented when the screen changes or when they move to a new item within a screen. This allows the manager to detect the change and understand what response the computer is ready to accept. The presentation must be limited to only the information that is most appropriate for the task at hand. The presentation of two much speech information will only confuse the manager.

3. Reduce memory demands on user: The task of managing the clients case requires the manager to select from lists of descriptions for many questions in the fill-in form portion of the program. The descriptions of each item in the list must be available to the manager in a consistent and simple way. This consistency is also necessary for the selection of the item they want. One way to do this easily for SRPs is by putting each item description on a single line above the prompt line for the question.

4. Minimize user actions: The managers should not have to enter long specifications if selecting from a list of items, or use multiple key strokes for frequently used functions and moving between fields on a particular screen. The managers should be able to use short cuts if they want to select only a few items from a screen.

5. Permit easy reversal of actions: Managers should be able to reverse actions, "Undo" or clear out a mistake. This is very important in screen review systems. Many times users of SRP simply turn off the computer and start over because they cannot identify and correct a mistaken keystroke that put them into an unknown portion of a program. This could be a big problem on a large multi-user system. This means that the user must be able to easy identify mistaken actions and have the information and training to easily correct it.

6. Simple error handling: Errors when detected should move the user to the source of the error and not only identify the cause of the error, but also provide a suggestion on how to correct it. In the case of SRP this means moving the cursor to the incorrect item and placing error information in a consistent place on the screen.

Re-Design Recommendations

The re-design recommendations are based upon a 24 line x 80 character display using a standard terminal emulation program to access a Unix based operating system. The actual case management software runs on the Unix system and is accessed by the manager through the terminal emulation program running on an MS-DOS compatible computer. The screen review software used as the basis for this re-design is JAWS from Henter-Joyce.

The first task was to divide the screen up into 6 different areas which can be automatically monitored by the SRP. Two of the areas are used to identify the type of the screen and the particular item the screen that is selected for user action. There are four major types of screens which include a menu, fill-in the form, static information and a client list. Based on the type of screen the SRP can reconfigure itself to adapt to format of the information presented on the screen. By monitoring the item that is selected the manager can be prompted automatically as they move from item to item. The identification areas are on the top line of the terminal emulation screen.

The third area is a title area on the screen which consists of the 2nd through the 4the lines from the top of the screen. This area will contain information to orient the user to where they are in the claims program. This area will be automatically be spoken when it changes to alert the manager that a new screen has been presented. They will also be able to use one keystroke to re-read this area.

The general purpose area of the screen is used to display information relevant to the task people are trying to complete and consists of the 5the through 23rd line on the display. This area is used to display menu information, fill-in prompts, fill in options, client information and etc... Only one piece of information will be presented on each line of the general purpose area to allow the SRP to use its read line function to easily read it to the case manager. The information on each line will contain both the prompt and the managers current response.

The system message area consists of the first 50 character positions on the 24the line of the display. This area will be used to display system messages and also provide error identification and correction information. The message area will automatically speak if it changes when the message is presented and can be repeated with a single key stroke.

The last area monitored on the screen is similar to the system message area, but is used to present supplemental information about some items for the fill-in forms area. This area will also automatically speak if a change occurs in it and can be repeated with a single keystroke. This area is the last 30 characters on the 24the line of the display.

In summary the first two areas are used to direct the configuration of the SRP and to direct the reading of information in the general purpose area. They are never read themselves since they are basically codes to the SRP. The title, system message and supplemental area are spoken automatically when new information is presented in their area of the screen and can all be repeated with one keystroke. The general purpose area is designed so that one complete piece of information is contained per line.

Menu Screen

The menu screen required few modifications from a layout point of view from the original design. Each menu option was currently displayed on one line so it can easy be read by the SRP. The information only needs to be shifted so the that the title and menu information are in the correct positions of the screen. The title of the menu must be moved into the title area, and the menu options and prompt into the general purpose area. The menu screen and prompt identification cues need to be added to the top line of the screen.

The major recommended changes for the menu have to deal with the selection of menu options. The current technique is to enter a number that corresponds to a particular menu item and a then select the "enter" key to execute the menu option. In addition to this number selection technique, it is recommended that a letter selection technique should also be used to select menu options. The letter should be associated with the function of the menu option. For example "A" to start a new Application and "C" for Closure of a client. This is also compatible with the menu system used in WordPerfect which is the wordprocessing program the managers will be using. This reinforces the consistency of commands within the programs the managers are using. The menu system can also be enhanced by allowing the users to scroll through the menu options. As the user types the up and down arrow keys the menu options would be spoken and the user could select the current option with the enter key.

Fill-In Screen

The fill-in screen re-design requires many more changes than the menu screen. The major problem with the original design was that most of the fill-in screens had multiple columns with inconsistent column widths. This inconsistency was not only between different fill-in screens, but also many times within a single screen. The inconsistent column widths ruled out the use of framing or windowing capabilities of the SRPs to limit speaking to one of the columns. The redesign recommends that only one column of information appear on fill-in form screens. The information should also be centered on the screen to facilitate viewing by the sighted managers. This not only improves use with SRPs line reading capabilities, but is also less confusing to the sighted managers. Even though this recommendation leads to an increase in the overall number of screens from the original design, it will be easier for occasional users to complete the task. This is due to not having to extensively search or know the configuration of each screen to determine which actions or options are required for that screen.

A frequently appearing fill-in item is a list of client characteristics and the manager must select either one item from the list or check each item that applies. In these cases the manager receives a prompt with a list of the options listed below the prompt. The user selects an option by typing a number corresponding to the number code at the prompt or by placing an "x" next to the item prompt. The recommendations ask that these types of item be treated like a menu. The menu style of interaction includes the addition of letter codes and the ability to scroll through options with the arrow keys to listen to and select items from the list.

Conclusion

Currently the software re-design recommendations are under consideration by the system developers. The design recommendations are not specific to JAWS screen review program, but can also be implemented with other screen review programs with auto-monitoring and speaking features. Many screen review systems have these features. These recommendations will also facilitate the usability of the system by all the case management staff. By reducing visual complexity and moving important information closer to the middle of the screen and the sighted managers can direct their attention to the completion of the task.

References

1. Potosnak, K. M.: Designing Ergonomic User-System Interfaces. The Koffler Group 1987.

2. Sceneiderman, B.: Chapter 2: Theories, Principles and Guidelines in Designing the User Interface. Addison-Wesley 1987.

3. JAWS Screen Review Software: Henter-Joyce Corporation. St. Petersburg, Florida 33716.

Jon Gunderson, MS
Gunderson Computer Access & Training
513 N. Franklin Ave #3
Madison, Wi 53705

The Assistive Dining Device: A Tool For Mealtime Independence

Carrie Brown, Ph.D., Maggie Sauer, M.S., Association for Retarded Citizens of the U.S., Arlington, TX
Al Cavalier, Ph.D., University of Delaware, Newark, DE
Eric Frische, B.S.E.E., Catherine Wyatt, Association for Retarded Citizens of the U.S., Arlington, TX

ABSTRACT

The Bioengineering Program has developed the Assistive Dining Device (ADD) to assist persons with physical and/or cognitive limitations to independently feed themselves. Taking the factors described below into consideration, the Assistive Dining Device was designed to make minimal cognitive and motoric demands on the user. Persons with impairments due to cognition, quadraplegia, spinal cord injury, cerebral palsy, the normal aging process, arthritis, and other neurological impairments represent individuals for whom the ADD may provide needed assistance during mealtime.

INTRODUCTION

Mealtime is universally recognized as an opportunity for relaxation and for socializing with friends and family. Until recently, however, mealtimes for persons with severe handicaps generally were regarded as dissatisfying, distasteful chores that caregivers had to perform several times daily. A caregiver's role at mealtime was to insure that a sufficient amount of nutrients were provided to the person they were assisting at mealtime. In many cases, one caregiver had multiple people to feed in the hour or so allotted for the meal. In the interest of time, meals concentrate on the delivery of food as rapidly as possible with little time for interaction with staff or peers by the person eating. Ohwaki and Zingarelli (1988) recently studied the mealtime practices at a skilled nursing care facility serving persons with severe multiple handicaps. Their survey results showed that feeding persons with severe multiple handicaps was time-consuming and the dignity of the mealtime experience was often sacrificed for expediency. According to staff members, the mealtime duration recorded in this survey, although lengthy, were less than sufficient to meet the clients' needs for social interaction.

While a variety of "feeding" devices are currently available to consumers, the available technology remains prohibitive to many users with severe physical and/or cognitive limitations. The available technology requires: 1) a moderate amount of cognitive planning in order to sequence the operations of the device, and/or 2) a good deal of trunk control and neck mobility. Many consumers complain that they would rather be fed by someone than expend the energy and time required to do it with the device (Kreckman & Sheredos, 1980)(2).

Robotics offers an additional avenue for independent eating. Presently, however, robots that have been evaluated as mealtime aids are excessively large, extremely expensive, and very fragile (Hall, Glass, Hammel, Leifer, & Perkash, 1987 (1); Michalowski, Crangle, & Liang, 1987(3); Park & Leifer, 1986(4); Schneider, Schmeisser, & Seamone, 1981(5); Seamone & Schmeisser, 1986)(6).

THE DESIGN

General Description

The ADD is portable, computerized, light weight, and durable. All motors and mechanisms are completely sealed so the ADD can be easily cleaned. The ADD utilizes standard 1/8" radio jacks to enable the user to control the device with any single switch which best accommodates the physical abilities of the user. For maximum portability, the device runs on internal rechargeable batteries or from a wall socket adapter. Set-up and adjustments to the ADD are simple to enable caregivers and mealtime partners from a variety of settings to easily use the device.

The ADD design has emanated from extensive field testing as well as clinical and engineering considerations. Consumers served as consultants to technical and clinical staff regarding device design. The device consists of four major sections; the base, the mounting arm, the device head (with accessories- napkin holder and cup holder), and the bowl.

Base

The base provides a means to clamp the device to the table and contains the necessary batteries and electronics. The electronics consist of a controller, the batteries, motor drivers and various switch inputs.

Mounting Arm

The arm enables the device to be positioned in front of the user within a two foot diameter vertically or horizontally. This range of motion permits the device to be positioned appropriately to meet a variety of users needs as well as accommodating individuals who are bedridden.

Device Head

The device head supports the bowl and accessories and contains the motors to turn the bowl and manipulate the spoon. Three motors drive the device: the bowl rotation motor, the spoon rotation motor, and the spoon extension motor. The bowl rotation motor rotates the bowl to the desired food selection. The spoon rotation motor moves the spoon down into the food. The spoon extension motor linearly extends the food out to the user. Gearing for the bowl rotation and spoon advancement can be plastic due to low torque requirements.

Bowl

The bowl is clear and partitioned into three sections. Each section is approximately 2.83 in. deep. The depth of the partitioned bowl insures the placement of food on the spoon as it scoops.

The bowl is suspended on a support arm in front of the user. The position and transparent bowl design permit the user to easily view the device during the eating process and to know what food selections are being offered.

Operation

When the food selection is made, the spoon dips into the bowl, scoops up the food, and presents the food to the user. The user must lean forward slightly and remove the food. A sensor on the spoon allows the device to know when to retract the spoon by sensing when the user is touching or has touched the spoon. The ADD is then ready to accept the next food choice.

METHOD OF OPERATION

The modes for operating the ADD, are as follows:

The **Two Switch** mode of operation permits the user with the physical ability, to control the device using two switches. One switch is used for bowl rotation while the second switch is used to control food presentation.

The **One Switch** mode of operation is for the user who can either cognitively or functionally make use of only one switch. It allows the user to rotate the bowl to the food of choice and make a selection. The first switch activation stops the bowl. The spoon automatically presents the food selected. The spoon will wait to be touched before retracting, and pauses until the next switch activation.

The **Fully Automatic** mode of operation is designed for the person who either cognitively or functionally cannot use a switch. The ADD bowl rotates to a selection and the spoon presents the food. After a time delay, if spoon contact is not detected, the food is returned to the bowl, the next selection is made, and the pattern is continued until spoon contact is detected. The ADD continues to automatically present food until spoon activity ceases. The cycle is repeated throughout the meal.

DATA COLLECTION AND ANALYSIS

A chronological report is generated of all system activity. Subsidiary reports are generated from the chronological report detailing specific switch, bowl and spoon activity. The report formats were designed to assist clinicians and caregivers in evaluating the users performance with the device.

DEVICE DEVELOPMENT

The ADD underwent two levels of prototype development before the final prototype was ready for final field tests: manual and computer controlled. Developing different prototype levels allowed project staff to test, research and refine the ADD as field testing progressed and additional information was obtained.

FIELD TESTS

The field test subjects for the Assistive Dining Device were children and adults with mental retardation and other disabilities who reside in the Dallas/Fort Worth area. Clinical and technical research questions were formulated to address device effectiveness and overall design. Significant data was taken from field test studies to improve device operation.

FUNDING SOURCES

The design and development of the Assistive Dining Device was made possible through funding from the ARC Research Fund, the Meadows Foundation, Zeta Tau Alpha Fraternity and ARC Washington.

References

1. Hall, K., Glass, K., Hammel, J., Leifer, L., & Perkash, I. (1987). Evaluation of a table top robotic aid for quadriplegics. Proceedings from the Tenth Annual Conference of the Rehabilitation Engineering Society of North America. Washington, DC: RESNA, 776-777.

2. Kreckman, J., & Sheredos, S.J. (1990). VAREC Progress Report - Winsford Feeder. Bulletin of Prosthetics Research, 17, 140-143.

3. Michalowski, S., Crangle, C.L., & Liang, L. (1987) Experimental study of a natural-language interface to an instructable robotic aid for the severely disabled. Proceedings from the Tenth Annual Conference of the Rehabilitation Engineering Society of North America. Washington, DC: RESNA, 773-775.

4. Park, H., & Leifer, L.J., (1986). Integrated sensory perception for rehabilitative robotic aid. Proceedings from the Ninth Annual Conference of the Rehabilitation Engineering Society of North America. Washington, DC: RESNA, 179-181.

5. Schneider, W., Schmeisser, G., & Seamone, W. (1981). A computer-aided robotic arm/worktable system for high-level quadriplegics. Computer, 14(1), 41-47.

6. Seamone, W., & Schmeisser, G. (1986). Evaluation of the APL/JHU robot arm work station. In M. Donath (Ed.), Proceedings of the Ninth Annual Conference of the Rehabilitation Engineering Society of North America. Washington, DC: RESNA, 252-253.

Carrie Brown, Ph.D.
Bioengineering Program
Association for Retarded Citizens
of the United States
2501 Avenue J
Arlington, TX 76006

P1.1

A CUSTOMIZED HEADREST FOR PRESSURE RELIEF AND LATERAL SUPPORT

Kathryn E. Kreiter, MSBE, David Casement, BSME,
Christine Jasch, OTR/L, William Armstrong, MS
Rehabilitation Institute of Chicago, Chicago, IL

ABSTRACT

The design of a headrest for use by individuals with C1-2 level quadriplegia is presented. It is custom-made for each client using commercially available hardware so that its position is adjustable in three planes. Because of its custom fit and adjustability, this headrest effectively provides both pressure relief and adequate posterior and lateral head and neck support, which maximizes the user's function. Fabrication details are provided so that this headrest can be duplicated.

BACKGROUND

Persons with C1-2 spinal cord injuries need adequate head and neck positioning for comfort and function. Maintaining proper neck position is crucial for the comfort of persons who are ventilator dependent. Adequate head support is needed for operation of wheelchairs using a sip-and-puff controller, or for operation of environmental control devices which use pneumatic controls or other switches activated by the head (eg. mounted on headrest, or activated by cheek or tongue). Proper head position also enhances communication by allowing individuals in wheelchairs to make eye contact with people in their environment. Moreover, appropriately designed lateral head support is important for good hearing. Some clients using headrests with lateral support can not hear well due to the lateral areas covering the ears.

Several individuals with C1-2 level injuries have complained of neck pain when using commercially available headrests (made by Otto Bock Industries, Inc., Miller's Rental and Service, La Bac). A need for customized neck support is apparent. Pressure relief is another critical issue. Common areas for skin redness and breakdown to occur are the back of the head and the ears. It is well documented that pressure sores are a serious and costly health concern.

STATEMENT OF PROBLEM

A headrest is needed which will provide posterior and lateral head support. It will provide support at the temples but will be cut out around the ears. Thus, the size and shape of the head support will be customized for each individual, in order to optimize head position and maximize function. The headrest will provide adequate neck support to decrease the occurrence of neck pain and development of deformities. In order to provide pressure relief, its inner surface will be lined with ROHO products.

Additional design goals for this product are that it can be fabricated quickly in-house, using commercially available hardware which is adjustable in several directions. Finally, the headrest should be cosmetically pleasing and unobtrusive.

RATIONALE

This custom headrest was designed because several commercially available headrests were tried with high level clients without success in meeting the above mentioned requirements.

DESIGN/DEVELOPMENT

A similar head support design was first developed at Sheppard's Spinal Care Center in Atlanta, GA. Occupational therapists at this facility adapted Sheppard's design by incorporating bilateral cervical support into the headrest shape. They also requested a different hardware attachment to allow for more flexibility in head and neck positioning. The Rehabilitation Engineering Department attached commercially available hardware made by Otto Bock Industries, Inc. to this head support so that it could be installed on the linear seating systems typically issued at this facility. Since the majority of headrests issued by rehab engineering are from Otto Bock, both this facility's therapists and consumers will be familiar with this equipment.

The head support piece is formed in the following manner. First, an orthoplast mold is taken of the individual's head and neck. This is covered with 1-1/2" thick T-foam, which will provide relief for the ROHO bulbs. Using the orthoplast and foam mold, a pattern is made to determine the size and shape of the headrest necessary to provide the indicated lateral and posterior support. This pattern, with a shape similar to that shown in Figure 1, is cut out of 1/4" thick ABS plastic using a band saw. This is heated in an oven at 350 degrees for approximately 8-10 minutes, then formed around the orthoplast mold. Note: Do this molding in a well ventilated area.

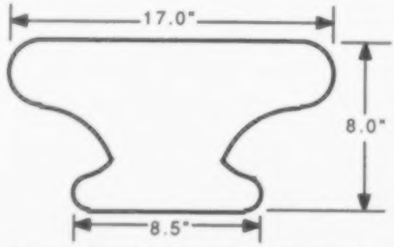


Figure 1. Sample headrest pattern with dimensions.

Commercially available hardware, made by Otto Bock Inc., which allows positioning adjustments in the sagittal plane and around all three axes, is attached to the headrest. The ball and rod are attached by drilling three body-sized holes for 10-32 T-nuts in the center back of the plastic head piece using the collar as a template as shown in Figure 2. A 1/2" diameter hole, in which the ball rotates, is drilled and centered between the three T-nuts. Three 10-32 x 1" machine screws are used to secure the ball and rod to the plastic. The square rod is inserted into its receptacle in the Otto Bock hardware. The seat plate assembly is then attached to the backrest of the client's wheelchair seating system. The mounted piece is shown in Figure 3.

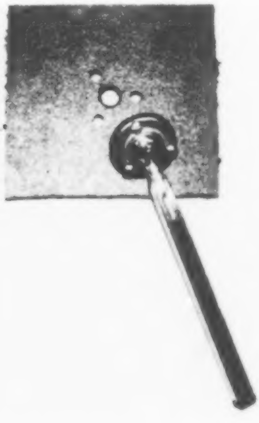


Figure 2. Attachment hardware used is made by Otto Bock Industries, Inc., part no. 430F7.

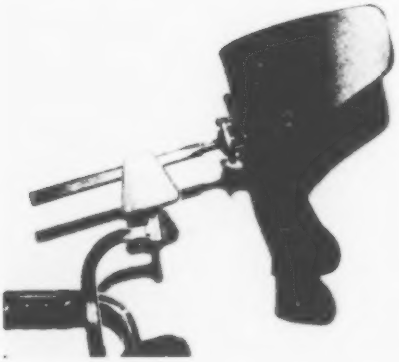


Figure 3. Headrest mounted on hardware.

Finally, the inner (concave) surface of the headrest is covered with loop velcro. Custom ROHO bulbs are attached to this surface. Both 1" and 2" ROHO bulbs, which are inflated through valves, and the 1" Single Cell (individually sealed) bulbs can be used. The pattern and size of ROHO products used is determined according to each individual's needs. The finished piece is shown in Figure 4.

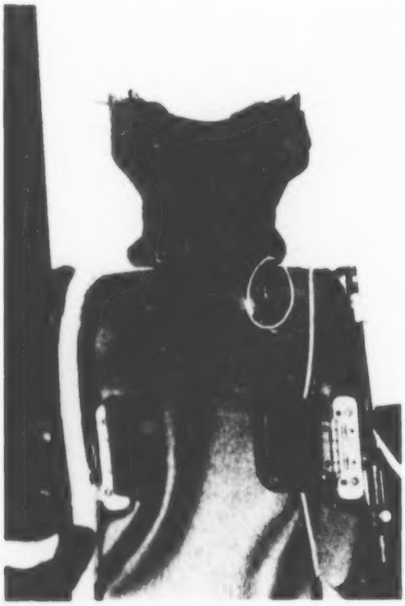


Figure 4. Headrest complete with ROHO bulbs.

EVALUATION/DISCUSSION

The first client to use this headrest did not receive adequate support from the cervical region. As a result, he experienced discomfort in his neck. A foam cushion, contoured to the client's occiput and neck, was fabricated and placed under the ROHO Single Cell cushion. This provided him with enough support so that he no longer experienced the discomfort. Since the lateral support of the headrest kept the client's head positioned within his range of control, he was able to operate his wheelchair using a sip-and-puff controller. The headrest also prevented the recurrence of an occipital pressure sore which the client previously had.

The second client to receive this headrest exhibited asymmetrical head placement, consistently leaning to the left side. To achieve midline head positioning, the occupational therapist used 1" ROHO bulbs on the right side and 2" ROHO bulbs on the left side in a custom pattern on her headrest. As a result, the headrest provided the support necessary to aid in preventing the development of neck deformities.

CONCLUSION

The headrest is a good solution in providing pressure relieving, posterior and lateral head and neck support for individuals with high level spinal cord injuries. It has also been used successfully with high level head injured individuals and may be appropriate for some ALS, MS or MD clients as well. It is custom-made to fit each client, yet is constructed using commercially available components. The design can be duplicated using tools commonly found in most rehabilitation engineering or occupational therapy departments.

SUPPLIERS:

OTTO BOCK Orthopedic Industry, Inc.
3000 Xenium Lane North
Minneapolis, MN 55441
(800) 328-4058

ROHO Incorporated
P.O. Box 658
Belleville, IL 62222
(800) 851-3449

Kathryn E. Kreiter, MSBE
Rehabilitation Institute of Chicago
Rehabilitation Engineering Department
345 E. Superior St. - Room 1441
Chicago, IL 60611
(312) 908-8566

DRIVER'S EDUCATION FOR POWER MOBILITY: PART II

Aimee J. Luebben and Lisa J. Young
Community Services
Belleville, Illinois

ABSTRACT

Regardless of the location in which a new power mobility device is prescribed and fitted, training of the first time user of power mobility is often an issue in community agencies, since the bulk of training, particularly the fine tuning of skills, takes place in this location. For many community agencies there is a formal mechanism which allows the addition of specialized programming customized to an individual. This paper describes a community based solution to address the independent mobility skills training necesary for the first time user of power mobility.

BACKGROUND

When designing training programs for first time power mobility users, community therapists encounter clients who are on a continuum from the optimal case to the worst case scenario.

In the optimal case of a student receiving a power mobility system for the first time, community therapists are part of the evaluation process and decision making. Whether handling the evaluation, funding, delivery and training completely within the community agency or contributing necessary information to a seating and wheeled mobility team outside of the facility, the community therapists are aware of the decisions made and timing of delivery to provide the transition needed in the community setting.

The worst case scenario is a morning call from a frantic teacher who finds the student on the schoolbus in a new power wheelchair. The bus driver, angry because he had not been notified to install appropriate tiedowns, has to show the teacher how to activate the wheelchair. Since school personnel including the community therapist were not notified, the therapist makes emergency arrangements to change her schedule for the week to work immediately with the teacher and student.

In the former case the therapist had time to confer with the transportation company before the power mobility system was delivered, making certain the bus lift was safe and tiedowns were appropriate. The power mobility training program was implemented from the first day with school personnel and family members aware of roles and assignments. In the latter case it was necessary that training be deferred until the safety issue was addressed.

OBJECTIVE

Training of the first time user in power mobility is often an issue in community agencies, since the bulk of training, particularly the fine tuning of skills, takes place in this location, away from hospital based evaluation clinics and dealer showrooms. The Individualized Education Program (IEP) is the mechanism available in school based programs to provide training in specific areas customized for each person. The objective was the formalization of an IEP amendment with a goal and related objectives to serve as a generic power mobility training program to be implemented with the introduction of a new power mobility device for a first time user.

APPROACH

L., an 18 year old woman with a diagnosis of cerebral palsy resulting in spastic quadriparesis and athetoid movements, is enrolled in a public high school and assigned a full time aide. In February 1990 there was a meeting of the team of school staff, family members, and funding sources to discuss L.'s successful completion of a trial period power mobility driver's education program (1). Since L. was proved successful during the 60 day trial period in a Jay Seat and Jay Back that had been customized for her positioning and functional needs, a similar seating system was requested. After funding was authorized in May 1990, the therapists had contacted the transportation company regarding the change in L.'s wheelchair and requested that work start on researching and installing new bus tiedowns.

L.'s new power wheelchair was ready to be delivered in August. Since L. was enrolled in an adult training program for the summer, school staff had arranged to consult to the summer program. To ensure that L. had adequate skills in the new device, the funding source had requested that the wheelchair not go home until L. had passed a specific training program. Since L. had not been in a power mobility base for six months, the summer program was given a copy of the trial period training program (1) to use as a refresher. In the three weeks remaining before school started, L. regained the skills she had learned in the previous winter. At the end of August the school therapists met to design a mobility training program to build on the skills learned in the trial period.

RESULTS

A meeting to amend L.'s IEP with the Power Mobility Driver's Education Program was held. Adding the new program on the IEP is a mechanism that formalizes the roles and expectations of all the school members as well as delineates a student's performance completion competencies. The Power Mobility Driver's Education Program consists of the goal: to improve school related mobility skills, and 12 objectives: to maneuver around groups of standing and talking people, to follow behind a group of students for at least 100 feet between classes, to maneuver up and down a ramp without stopping when distracted, to make the transition to and from a sidewalk to uneven terrain, to turn into and out of an entrance, to maneuver around six obstacles within a hallway without bumping, to maneuver around six obstacles in a classroom without bumping, to move to a location at a table/desk, to move into position to be picked up by the bus, to cross a street without stopping when distracted, and to indicate to another person to open a door. By the end of September 1990 L. had reached the completion criteria of successful performance on three consecutive data collection days on all 12 objectives. With the funding source's approval, L. took her new seating and power mobility system home.

DISCUSSION

For community therapists this is an example of an optimal case. Working in tandem with funding agencies, classroom personnel, summer program staff, transportation representatives, as well as L. and her family, community therapists assisted L. in the utilization of a seating and wheeled mobility system that was appropriate for her positioning and mobility needs.

To lessen the effects in the worst case scenerio, the safety issues must be addressed first. The transportation company must be notified to install appropriate tiedowns and the new seating system must be evaluated for retrofitting needs. Oftentimes hospital based evaluation clinics overlook long bus rides on bumpy rural roads or pothole covered urban streets when decisions are made regarding the components of a seating system. If retrofitting is needed, additional funding must be secured. Third party reimbursement sources, obligated to curb escalating health care costs, realize that much retrofitting is an unnecessary expense (2) and are sometimes reluctant to authorize additional funding.

After the safety issues have been resolved, training may start. The student who received the mobility device without completing the trial period power mobility training program (1) has both mobility training programs added to his or her IEP. The trial period program works to improve general mobility skills while the standard training program fine tunes these skills to improve precision and speed in and around the school.

REFERENCES

1. Luebben, A.J. and Young, L.J.: Driver's Education for Power Mobility: A Community Approach. Proceedings of the Thirteenth Annual Conference on Rehabilitation Engineering, Washington, D.C.: 1990.

2. Luebben, A.J. and Young, L.J.: Retrofitting: An Unnecessary Expense. Proceedings of the Twelveth Annual Conference on Rehabilitation Engineering, New Orleans: 1989.

ACKNOWLEDGEMENTS

This work was supported by Franklin-Jefferson Counties Special Education District, Benton, IL; Mamie O. Stookey School, Belleville, IL; Coleman Tri-County Services, Harrisburg, IL; Williamson County Special Education District, Marion, IL; and Bissell Healthcare Corporation, Grand Rapids, MI.

Aimee J. Luebben, MS, OTR/L
Community Services
506 Freeburg Avenue
Belleville, IL 62220
(618) 235-8460

P1.3

A COST-EFFECTIVE APPROACH TO EXTENDED ASSESSMENT AND PRELIMINARY TRAINING FOR POWERED WHEELCHAIR CONTROL

Thomas L. Grey, M.S.
Assistive Device Center
California State University, Sacramento

ABSTRACT

Extended assessment for powered mobility control is sometimes required at many outpatient clinics, centers, etc. A cost-effective, four-phase program was developed to address this requirement. Each phase provides data on client performance. The program includes a cost-effective way of providing preliminary powered wheelchair training with a candidate control system without the need for a powered wheelchair.

BACKGROUND

For some clients, the process for powered mobility controller selection can be very time consuming. The client may show potential at more than one control site and for more than one type of controller and there may be positioning issues that must be temporarily addressed. This becomes a problem for outpatient clinics and centers that must accomplish this process within a fairly short assessment period, e.g., during a three to four hour appointment.

For these clients, it is necessary to provide an extended period of assessment in order to determine the best type of controller. Two main problems with an extended assessment are additional cost for clinician time (critical for smaller clinics whose other services cannot absorb this cost) and inconvenience for the client if the client lives far from the clinic and/or transportation is difficult to arrange.

An extended assessment program for a client who met this general description was developed with assistance from the assessment team. An additional benefit of this program is that it also provided initial training in the use of the controller that was recommended. The program takes advantage of existing resources for the client in order to reduce the cost of the program.

OBJECTIVE

The goal for this extended assessment program was to determine the best choice among two types of powered wheelchair controller for a particular client. The controller options, switched mini-joystick or head switch array, had been determined during a previous assessment, which did not allow time for determining the best option. Another factor was the client's strong preference for using his hand (mini-joystick) when the preliminary assessment findings indicated better control with his head (head switch array). Since additional funding for the extended assessment was requested from the agency who referred the client, a secondary goal was to keep the cost of this program to a minimum. Other resources (e.g., day programs, school, home, etc.) that the client had available were researched for inclusion into the program design to achieve cost reduction.

APPROACH

A four-phase program of extended control assessment was developed that relied on participation from the client's day program, which was willing to assist in the extended assessment program provided that it blended with the client's current activities. The day program director was also very interested in helping this client with achieving independent mobility. The general outline for this program is as follows:

1. Phase I: Collect data on use of mini-joystick with hand.
2. Phase II: Collect data on use of switch array with head.
3. Compare the data from Phases I and II and analyze.

4. Determine which controller shows greater promise for success with powered mobility.
5. Phase III: Use this controller to direct a partner to push the client's current manual wheelchair around a series of obstacle courses and collect data on performance.
6. Analyze Phase III data.
7. If manual wheel chair activity is successful, then go to Phase IV. If manual wheel chair activity is not successful, determine problem areas and develop recommendations to address those areas so that the client can be re-assessed at a later date.
8. Phase IV: Schedule clinic appointment to have client use controller with powered wheelchair. Collect data (including videotape) regarding client's reaction to and use of independent powered mobility.
9. Review all data. Discuss results with client, family, day program, and funder of assessment. Make recommendations for purchase of powered mobility and further training based on results and discussions.

A consistent partner was identified at the day program who received oral and written instructions and data sheets prior to each phase. The partner was asked to record data and provide subjective observations for all phases. Phases I and II consisted of a number of sessions involving the use of an Apple IIe computer with a program designed to provide user feedback and to collect data regarding the use of each controller (response time, switch holding time, and time to release after holding). The computer, software and controller were rented from the clinic for use at the day program at a nominal fee to address liability-for-damage concerns. Phase III was designed to provide a realistic simulation of powered mobility and was easily implemented at the day program. The client used the controller to indicate direction on a direction indicator box with sound feedback that was easily seen by the partner. Obstacle courses were graded from simple to more complex during a number of sessions. The partner was asked simulate the typical movements of a powered wheelchair (abrupt starts, finite stopping time, turning radius, etc.) in order to observe the client's reactions to these factors. During Phase IV, the client was set up in a powered wheelchair with the same controller. The client was then asked to go through a similar series of obstacle courses (straight line, right-angle turns, circles, avoid obstacles, etc.). Observations of the client's performance were recorded and the client was videotaped.

RESULTS

This program was implemented during the Fall of 1990. Phases I and II determined that the head switch array was the better controller and the client agreed (his initial preference had been for hand use). A problem was noted with the client's movement patterns with his head when using the computer, but it was felt that these movements would not be a problem during actual wheelchair use; therefore, the program continued to Phase III.

Results from Phase III were mixed. The main problem for the client involved not knowing how to use the switches to impart or enforce directional changes to get out of situations, e.g., stuck against a wall. This was to be expected since this was his first experience with any kind of independent mobility. Secondary problems involved the mounting and adjustment of the switch array; modifications to the switch array were designed that would eliminate these problems. The positive result was that the client responded well to instruction and experience with using the head switches to determine direction, go/stop, etc.; therefore, the program continued to Phase IV.

The Phase IV appointment lasted about two hours and involved two clinicians. At first, the client struggled with the feel and experience of the powered wheelchair. However, the client was able to adjust to the experience and eventually maneuver the wheelchair down hallways, around corners and people, and through wide (double) doorways. The increase in the client's self confidence during Phase IV was directly observable.

Recommendations were made for the purchase of powered mobility based on the results of this program. The client also benefitted from the preliminary training he received during Phased III and IV of this program as it is anticipated that he will need less training after he receives his powered wheelchair. The client and his family benefitted from knowing that he is able to learn new skills and achieve greater independence given an opportunity and proper support.

DISCUSSION

The phased, extended assessment program described above provides the objective and subjective measures necessary for control evaluation while containing cost. The fairly general nature of the program and its adaptability to various situations and resources make it easy to replicate at other sites.

The cost of the extended assessment was contained primarily by reducing the amount of time that the clinician(s) must spend with the client. While minimization of direct clinician contact with the client may be considered a drawback, the program presented here fosters greater understanding and cooperation with other people and programs that the client is involved with, which should be considered as desireable. It should be noted that the clinicians involved with this client were able to work with other clients and on other projects while the day program staff worked with the client; this increased the efficiency and productivity of the clinic.

Day program staff also benefitted from the exposure to formal wheelchair training processes. Plans are being made to incorporate some of the techniques learned into the wheelchair activities for the day program's other powered wheelchair users to help them refine their skills.

Thomas L. Grey
Assistive Device Center
California State University, Sacramento
6000 J Street, ECS-5025
Sacramento, CA 95819

SMALL IMPROVEMENTS IN SEATING HARDWARE

Charles J. Laenger
James H. Lee
Kaiser Rehabilitation Center
Tulsa, OK

Abstract

Attachment of devices and components to postural positioning systems is a perennial problem. Such attachments should, ideally, be easy to use, difficult to install incorrectly, functional and inexpensive. Some of the most difficult and frequent problems deal with securing positioning and quick disconnect of vests, knee blocks, pelvic restraints and other devices. Examples of devices developed and used in postural seating systems at this facility are presented herein.

Background

The smartest seating design-fabricator or engineer uses commercially available devices and components. But sometimes no commercial device is adequate.

Then the second-smartest engineer develops a new device, or improves an existing device taking full advantage of the ingenuity of his predecessors. Examples follow.

Problems and Solutions

A. Vest Attachment Plate

Problem: Straps that secure "butterfly vests" or shoulder restraints often exert downward pressure on the shoulders. Sometimes there are no convenient attachment points on the upper back of the wheelchair.

One Solution: A custom attachment plate was made from sheet Kydex - a heat-formable plastic used routinely by orthotists. Such a device was made for a LaBac, zero- shear power recliner back. See Photo #1.

A leg of the Kydex plate was threaded through the friction maze of a commercially available ABS plastic belt buckle; no screws were used. This provided a convenient, rigid, properly positioned quick-disconnect for a "butterfly" vest. Two of these devices are currently in use on one wheelchair.

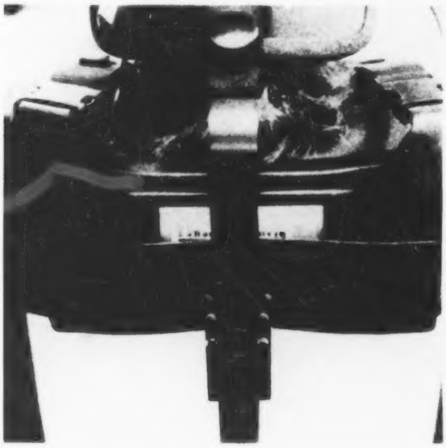


Photo #1. Butterfly Vest, Anchors and Quick Disconnects

B. Custom-Contoured SUBASIS Restraints

Problem: Commercially available SUBASIS bars do not always fit deformed individuals and few quick-disconnect options exist.

One Solution: For one client, a SUBASIS restraint was made with a 3/16 inch thick Kydex strap. See Photo #2.

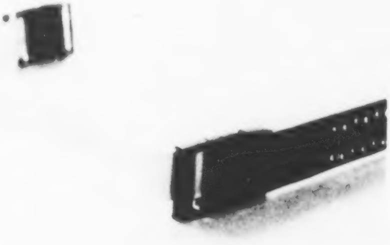


Photo #2. Custom-Contoured SUBASIS Restraint with Quick Disconnect

The Kydex strap was contoured to accommodate the deformity of the client and the shape of the Contour-U seating system. The Kydex strap was threaded through the friction maze of a commercially available ABS plastic belt buckle to assure repeatability of positioning and to provide quick-disconnect convenience. The mating part of the buckle was attached to the wheelchair by a Kydex strap with screw holes to permit initial adjustment and semipermanent attachment. The body of the Kydex strap was padded and covered with vinyl. The system has functioned satisfactorily with a difficult, highly spastic client. This device was patterned after an apparatus developed by Shaw at the University of Tennessee.

C. Knee Block Positioning and Quick Disconnect

Problem: Commercially available knee blocks are secured with belts which do not maintain proper positioning.

It is often necessary to custom contour the knee block insert to compensate for leg length discrepancy.

Two Solutions: This facility designed a telescoping positioning and holding system. The larger or receiver tube was secured under an Enduro manual wheelchair. The smaller tube was secured to the frame of the knee block. A detent or spring-loaded captive ball was used to properly position the assembly. This system has functioned satisfactorily for more than a year in a very harsh environment. Another system currently in development will use rigid Kydex straps and belt buckles. See Photos #3 & 4. A Kydex strap with regularly spaced holes will be used to attach one half of the buckle to the wheelchair.

Photo #3. Knee Block Positioning and Quick Disconnect

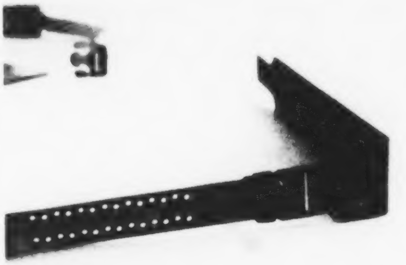


Photo #4. Knee Block Frame can be Formed Around Custom Insert

D. Thoracic Anterior-Lateral Support with Swingaway Feature

Problem: Some applications demand large, padded anterior-lateral chest supports for which there are no appropriate swingaway brackets.

Solution: This facility developed an anterior-lateral support for a very strong and active spastic cerebral palsied individual. A positive latching swingaway device was fabricated utilizing Millers hardware. See Photo #5. These supports have functioned satisfactorily for over a year in an extremely harsh environment. They have been invaluable in safely and properly positioning a very difficult client by constantly changing, non-professional care providers.

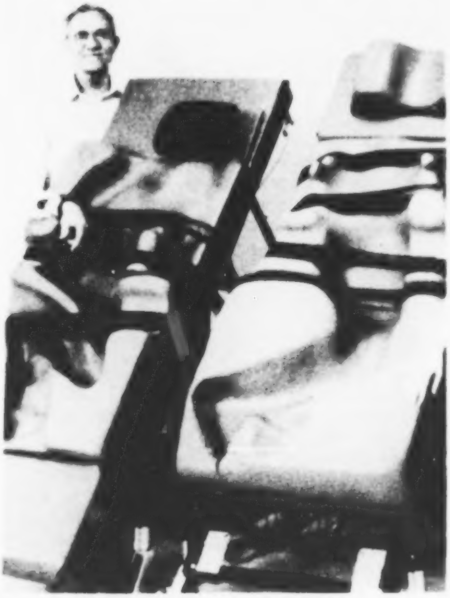
Photo #5. Large Custom-Contoured Anterior-Lateral Support with Swingaway Attachment and Positioning

E. Quick Disconnects for Linear Positioning Devices

Problem: Two linear positioning devices, after Kerry Jones et.al, were developed for two brothers. After the systems were delivered, the care providers asked for a quick-disconnect feature for removing the stretcher and cushion assembly from the wheeled base.

Solution: A gravity-loaded lock was installed at the point of rotation where the stretcher attached to the wheel base assembly. See Photo #6. Quick disconnect pins, captured-ball type, were installed at the point where the tilt brakes attached to the wheel base assembly. This equipment was recently put into service. Reliability and performance have not yet been determined.

Photo #6. Linear Positioning Devices for Two Brothers Frozen In Full-Body Extension. Quick Disconnects permit Separation of Stretcher and Base



Discussion

The need for better and less expensive fasteners and quick-disconnects for postural seating and mobility systems will continue forever. It is particularly important to have attachment devices that can be easily and correctly used by non-technical personnel but that can conveniently be adjusted by rehabilitation professionals. Hopefully, some of the devices described herein will be improved by others and made available as commercial products.

Acknowledgments

Funding for development of new rehabilitation-related devices at this facility is currently provided by The Mervin Bovaird Foundation. Bob Vanzandt, certified orthotist, generously provided consultation on materials and methods used in orthotics.

References

Cooper, David, Tredwell, Stephen, Roxborough, Lori, The MERU Rigid Pelvic Stabilizer for Postural Control, Proceedings RESNA 10th Annual Conference 1987, p 573-575

Jones, Kerry, Bazata, Cathy, Conyers, Bill, The Seating Challenge, Pin Dot News Special Edition, 1988, p 10-11.

Margolis S.A., Jones R.M., Brown B.E., The subASIS bar: an effective approach to pelvic stabilization in seated positioning, Proceedings of the 8th Annual Conference on Rehabilitation Engineering, p 45-47, June 1985.

Shaw G., Rigid pelvic restraint, Proceedings of the 8th Annual Conference on Rehabilitation Engineering, p 409-411, June 1985.

Charles J. Laenger
Rehabilitation Engineering and Orthotics
Kaiser Rehabilitation Center
1125 South Trenton
Tulsa, OK 74120
(918) 584-1351, ext. 7347

P1.5

A NEW METHOD TO ASSESS THE DYNAMIC REAR STABILITY OF OCCUPIED WHEELCHAIRS

George G. Majaess, R. Lee Kirby & Stacy A. Ackroyd-Stolarz
Division of Physical Medicine and Rehabilitation
Department of Medicine, Dalhousie University
Halifax, Nova Scotia, Canada

ABSTRACT

A new method was developed for the assessment of the dynamic rear stability of occupied wheelchairs. Studies were carried out by having each of 16 able-bodied subjects, seated in a wheelchair, rolling backward down a 3° ramp, guided by side-rails, and colliding with an obstacle at the bottom of the ramp. The desired extent of the tip was achieved by titrating the launching distance. The endpoint was indicated by a simple adjustable device. The pre-impact wheelchair speed was measured using a pair of photoelectric gates 20 cm apart. The mean (SD) speed at which a threshold tip was induced was 0.63 (0.06) m/s. The reliability ($n=10$) was $r=0.92$ ($P<0.001$). This technique is simple, safe, reliable and practical and it should have useful applications in the evaluation of wheelchair stability in both clinical and research settings.

INTRODUCTION

More than 750,000 people in the United States use a wheelchair on a regular basis (2). An estimated 3.3 % of them undergo a serious wheelchair-related accident each year, with falls and tips constituting by far the greatest proportion (2). Excessive wheelchair stability may hinder performance (1). Wheelchair stability is therefore an important consideration in wheelchair design and selection. Although standards have been developed for testing the static stability of wheelchairs occupied by test dummies (3), and for testing the dynamic stability of powered wheelchairs (4), to date there are no national or international standards for the testing of dynamic stability of manually powered wheelchairs. Some experimental work has been reported on dynamic forward stability (5,6), but none on dynamic rear stability.

In this study, we report the development of a method to assess the dynamic rear stability of occupied wheelchairs.

METHODS

Sixteen able-bodied subjects were studied with their informed consent. Tests were carried out using a 2.5-m-long plywood ramp, the surface of which was marked in 5-cm intervals starting from the bottom (Fig 1). Backward wheelchair tips were produced by having the occupied wheelchair (E&J Mirage), with the subjects' arms in their laps, descend the ramp by gravity alone, and come to a stop by colliding with a 19-cm-high metallic obstacle at the downhill end of the ramp. The degree of the ramp inclination (3°) was determined by pilot testing. To ensure a straight descent, such that both rear wheels struck the obstacle at the same time, 48-cm-high side-rails were used.

The threshold speed (TS) necessary to produce a defined tip of a predetermined extent is related to the wheelchair distance between the starting position of the wheelchair and the obstacle. This was titrated in 5-cm increments up the ramp until the TS required for tipping was found. A pair of photoelectric gates, 20 cm apart at the bottom of the ramp, turned a timer on and off, providing the time elapsed (to the nearest 0.001 s) for the wheelchair to travel the distance between the gates, allowing calculation of the speed (m/s).

The device used to indicate the endpoint (a threshold tip) consisted of a light sharpened rod which was fastened vertically to the rearmost aspect of the lower frame of the wheelchair, behind the rear-wheel axles. This location resulted in a descent of the rod with elevation of the casters (Fig 2). The extent of the desired tip was controlled by the distance between the lower end of the rod and a marking system (we used a strip of masking tape) mounted at the bottom of the ramp. For this study, the extent of caster lift from the ramp surface was set at 4 cm.

Reproducibility of the data was evaluated by repetition of the testing procedure at the detected threshold distances. A spotter was present at the bottom of the ramp, although the wheelchair was always far from a full tip with this incremental threshold method. When a greater extent of tipping was permitted or the endpoint was not approached in an incremental way (in pilot work), the violence of the tip and the risk of injury increased.

RESULTS

All subjects tolerated the procedure without undue anxiety and without injury or incident. The procedure could be performed by a single investigator in less than 5 minutes. The mean (SD) speed of the chair to induce a threshold tip was 0.63 (0.06) m/s. The reliability, based upon repeat testing of 10 subjects, was $r=0.92$ ($P<0.001$), and there was no significant difference between the data from the first and second tests using a matched-pairs t-test. The mean difference (SD) was 0.001 (0.031) m/s ($P=0.95$). The correlation with static stability testing was $r=0.007$ (not significant).

DISCUSSION

The testing procedure provides a simple, safe and reliable method to test the dynamic rear stability of occupied wheelchairs. The ability to control the endpoint (the extent of wheelchair tip) and the incremental approach add important safety dimensions by eliminating hazardous violent tips. The passive nature of this method, in comparison with having a subject propel a wheelchair up a ramp, provides a means by which anthropomorphic test dummies can be tested as easily as human subjects, especially if full wheelchairs tips are contemplated.

The lack of correlation between the static and dynamic rear stability testing data indicates that dynamic stability cannot be accurately predicted by static stability testing.

When comparing the stability of different subjects, the height of the wheelchair frame may vary due to some flattening of pneumatic tires with heavy subjects. This would produce a closer resting proximity of the metal rod tip in relation to the tape, causing the end point to occur with less backward tipping. This problem can be eliminated by adjusting the distance between the rod tip and the tape.

We hope that this new method for assessing the dynamic rear stability of occupied wheelchairs will be useful to clinicians and investigators involved in the evaluation of wheelchair safety.

ACKNOWLEDGEMENT

Funding for research was provided by a University-Industry grant from the Medical Research Council of Canada.

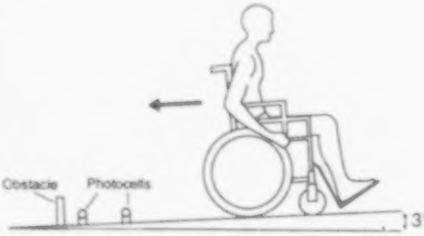


Fig 1. Occupied wheelchair rolling backward down the ramp. Side-rails are not shown.

REFERENCES

1. Brubaker, C.E.: *Ergonometric Considerations.* J Rehabil Res Dev, Suppl #2 2:37-48, 1990.

2. Calder, C.J., and Kirby, R.L.: *Fatal Wheelchair-related Accidents in the United States.* Amer J Phys Med Rehabil 69:184-190, 1990.

3. International Organization for Standardization (ISO), Guidelines for Application of Wheelchair Standards, *Determination of Static Stability*, 7176/1, 1988.

4. International Organization for Standardization (ISO), Guidelines for Application of Wheelchair Standards, *Determination of Dynamic Stability of Electric Wheelchairs*, 7176/2, 1988.

5. Kirby, R.L., Atkinson, S.M., and Mackay, E.A.: *Static and Dynamic Forward Stability of Occupied Wheelchairs: Influence of Elevated Footrests and Forward Stabilizers.* Arch Phys Med Rehabil 70:681-686, 1989.

6. Kirby, R.L., Maclean, A.D., and Eastwood, B.J.: *Influence of Caster Diameter on the Static and Dynamic Forward Stability of Occupied Wheelchairs.* Arch Phys Med Rehabil (in press), 1991.

George G. Majaess
Division of Physical Medicine And Rehabilitation
Department of Medicine
Dalhousie University
1341 Summer Street
Halifax, Nova Scotia,
Canada
B3H 4K4

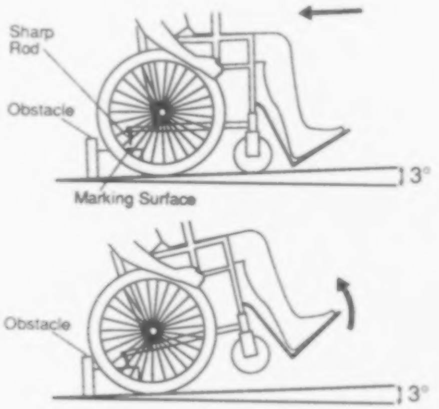


Fig 2. Device for determining the endpoint, a sharp rod attached to the rearmost part of the wheelchair frame just before tipping (top) and after (below).

P1.6

CUSTOM MOLDED SEATING AT NORTH DAKOTA'S DEVELOPMENTAL CENTER

Don Olson, Ken Reiss, Byron Poppenhagen, and Kevin Matheson
Adaptive Equipment Services (A.E.S.)
Developmental Center
Grafton, North Dakota

ABSTRACT

This paper describes the approach to provision of custom molded seating devices for persons who have severe physical disabilities. The current service is the result of nearly eight years of work and change involving clients, seating specialists, and therapists.

The service delivery system's components of information gathering, simulation, and fabrication are discussed.

The fabrication process is described in detail, as it represents a unique approach. The process offers advantages in wheelbase interfacing, client comfort, appearance, and cost savings.

INTRODUCTION

The Adaptive Equipment Services area has been providing on-site custom seating solutions for person who have severe developmental disabilities since 1982. Starting as a one-person operation, the program is currently staffed by a physical therapist, four Bachelor-level specialists, and two technicians.

Adaptive Equipment Services works closely with the Physical and Occupational Therapy Service areas to identify clients in need of customized seating devices.

Currently, 85 of the 223 persons who reside at the Center have significant spine and pelvic deformity. These individuals require custom molded seating devices in order to maximize comfort, manage orthopedic deformity, and enhance function.

Although commercial alternatives are available, providing on-site services to these individuals allows for greater customization, while reducing cost significantly.

INITIAL FITTING/SIMULATION

The fitting process uses an interdisciplinary team approach consisting of the client, a physical therapist, an occupational therapist, a seating specialist, a direct care provider, and other persons important to the client.

Information regarding the client's medical history, orthopedic status, daily routine, likes/dislikes, skills, transportation, and wheelbase requirements is gathered and discussed. Goals describing the expected outcomes of the equipment are outlined by the Team.

The fitting/simulation is done using the molded chair shown in Figure 1. The system uses vacuum dilatancy technology common to other commercially available simulators.

Once the client is positioned comfortably and the team is satisfied with the orthopedic and/or functional results, the client is transferred out of the simulator, and the next phase of the process begins.

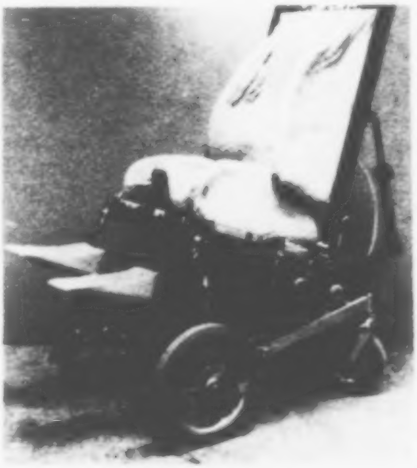


Figure 1

MOLD PREPARATION

The negative impression left by the client in the simulator is filled first with about one-fourth inch of plaster and water. The remaining void is filled using four (4) pound rigid urethane foam. Once set up, the vacuum is released and the positive model is removed from the simulator.

In nearly every case, some modification of the positive model is necessary in order to achieve desired orthopedic and comfort outcomes. For instance, plaster is often added to bony prominences at risk for skin breakdown, allowing for greater relief in the seating device. Care is taken to ensure a close fit along the lateral trunk, especially under the axilla, where a loose fit can cause discomfort along the upper arm.

Flexible components of scoliosis present can be corrected while in the device by taking plaster away from areas on the mold where corrected forces are desired. In fact, for adults who have collapsing scoliosis, a molded seating insert has been used successfully as an alternative to spinal bracing via a thoracolumbosacral orthosis (T.L.S.O.)

FABRICATION OF SEAT AND BACK

For adults, the seat and back portions are made separately by sectioning the positive mold at the waist. For smaller children, the insert can be formed in one piece.

First, one-half inch of a medium density closed cell foam is placed with tape. Then, using vacuum assisted thermoforming techniques, 3/16 inch ABS or Kydex plastic is drawn over the mold, taking the shape of the individual. The foam serves as a barrier between the person and the rigid plastic, and improves comfort.

INTERFACING

Interfacing of the seat and back to each other and to the wheelbase is custom. Square or round steel tubing of one-half to one inch is used to join the seat and back components, using the intact positive model as a guide in order to maintain the seat to back relationship. The metal is bent and welded, conforming to the contours of the seat and back, as seen in Figure 2. Note that enough space is allowed between the metal supports for x-ray documentation of the spine.

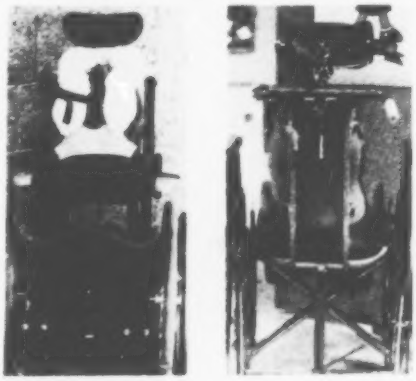


Figure 2

Interfacing the insert to the wheelbase can be simple, or complex, depending on individual needs. Some people require only that the insert be secured firmly the base, in which case drop hook interfacing is sufficient.

Others may need the insert to detach from the base, or they may require recline-in-space on a base that does not offer this feature. These features can be added to standard bases, using custom interfacing.

Thus, this method of interfacing allows for flexibility in wheelbase selection, and can be especially useful in institutional settings where funds to purchase appropriate wheelbases for all clients is not available.

SUBSEQUENT FITTINGS

Once the seat and back are formed and interfaced to a wheelbase, a second fitting with the client is held. During this session, the back is marked and excess plastic is trimmed for comfort. The seat is checked for proper depth.

Pelvic stabilization is discussed. We have used both standard pelvic belt support and rigid pelvic stabilizers on these systems. Pelvic belts are placed directly into the seat and are adjustable underneath using two cam-lock buckles. Hardware for rigid supports is welded directly to the seat interface.

Other supports for the anterior trunk, upper extremities, lower extremities, and head are also addressed at this session.

SYSTEM COMPLETION

The last phase of fabrication involves vacuum forming upholstery to the seat and back, painting all metal interface components, and installing additional supports discussed at the second fitting.

Delivery of the system is done at a final fitting session. Plans for sitting time, staff inservice, and follow-up are made at this time.

DISCUSSION

The total time from initial fitting to delivery varies with complexity but is about ten (10) working days. The cost of each system varies as well, but is about $1200 to $1500 for materials and labor. This compares to about $2500 for a device obtained commercially through a private vendor.

Regardless of cost benefits to the agency, the benefits to the client can be seen in increased customization, timely modification, and overall comfort. The low profile fit and upholstered surfaces improves the individual's appearance, according to staff and families we have served.

The development of this service, purchase of equipment, and hiring of staff has occurred gradually over the past eight years, so impact to the agency's overall operating costs has been modest.

The cost to an agency to develop on-site services would be high initially, but could prove feasible in the long term, resulting in improved client service.

ACKNOWLEDGEMENTS

The authors wish to thank the clients, staff, and Administration at the Developmental Center for their support in the development of the Adaptive Equipment Services area.

Also a big thanks to Glen, Jack, and Al, whose contributions are invaluable to people who live at the Developmental Center.

Contact Don Olson, PT, Director
Adaptive Equipment Services
Developmental Center
Grafton, ND 58237
(701) 352-2140, ext. 234

P1.7

Development of a Protective Helmet for Persons with Disabilities

S.E.Ryan, G.Belbin, M.Slack, S.Naumann, and R.Moran
The Hugh MacMillan Rehabilitation Centre
Toronto, Ontario, Canada

Abstract

This paper describes the development of a system for economically dispensing protective headwear to provide effective head and facial protection for individuals who frequently fall.

The new helmet consists of three parts which must be adjusted, located and secured in place by an orthotist during a fitting.

Results from biomechanical testing, clinical trials, and a preliminary cost analysis indicated that the research helmets can offer the same degree of protection as custom-fabricated versions yet be dispensed through a headwear clinic in about two to three hours for less than 40% of the cost.

Background

Many children and adolescents with neuromuscular and seizure disorders have falls which can result in severe head and facial injuries unless appropriate headwear protection is provided. Commercial sports helmets provide protection for the cranial vault, however, they tend to be uncomfortable to wear due to their weight and poor ventilation. In addition, the level of protection provided by this type of headwear is inappropriate in many cases.

Custom-fabricated helmets are functional alternatives to the commercial systems available (Belbin and Giavedoni, 1987). This approach has proven to be clinically effective in providing appropriate protection for the head and face.

It was proposed, however, that the same degree of protection could be afforded to a many individuals faster and at a reduced cost if a modular design, custom-fitted version could be created (Hill et al, 1987). This paper describes the completion of the project which was undertaken to develop this approach to providing functional headwear.

Design and Development

The new helmet developed consists of three parts: an anterior section, posterior section and a chin protector. Each part is comprised of a hard polyethylene outer shell and a soft polyethylene foam liner. Both parts are industrially fabricated in two sizes to accommodate children from ages 5-19 years. The anterior aspect of assembled helmet is configured to extend out to provide clearance for the face following a forward fall (Figure 1).

To minimize the number of sizes required, while creating a helmet which maximized the number of individuals served, two sizes were created: a junior size to fit children nominally 5-12 years of age and a senior size for individuals up to 19 years old. The anatomical criteria for determining the appropriateness of the research helmet for individuals were related to measurements of head circumference, head length and head breadth. The recommended ranges were specified for both sizes to provide anthropometric guidelines for the orthotists fitting the research helmets. Individuals with head measurements outside these ranges were generally judged to be candidates for the custom-fabricated helmet.

Evaluation

(a) Biomechanical Testing

Both quantitative and qualitative biomechanical tests were conducted to evaluate the protective nature of the helmet:

At the biomechanical test laboratory at Cooper Canada Limited, the helmet was tested to evaluate its' ability to meet the impact attenuating requirements of the Canadian Standard Association (CSA) for hockey helmets. For the cranial areas tested, the transmitted forces measured were below the threshold limits set in the CSA Standard.

To evaluate the effectiveness of the helmet in offering facial protection, an impact test rig was designed and constructed. Since no valid acceptance limits for evaluating this aspect of protection were available, the relative performance of the research and custom-fabricated helmets were investigated. Imprints of headform excursion demonstrated that a properly fit production helmet appeared to provide facial protection at least equal to that provided by the custom-fabricated version.

(b) Clinical Trials

Nine children having various neuromuscular and seizure disorders, and who were users of custom-fabricated helmets, participated in the clinical evaluation of the modular headwear. Initially, the children were measured to determine the suitability of the helmet based on anthropometric values suggested. For subjects judged suitable, the helmets were custom fit by one of the two project orthotists.

Clinical trial periods lasted six to ten weeks. The parents and their children returned to the clinic for a follow-up visit whereupon they were asked to judge specific features of the helmet and rate its performance. The project orthotists who performed the initial fittings inspected and evaluated the service condition of the devices. Clinical impressions of the post-trial fit were also solicited.

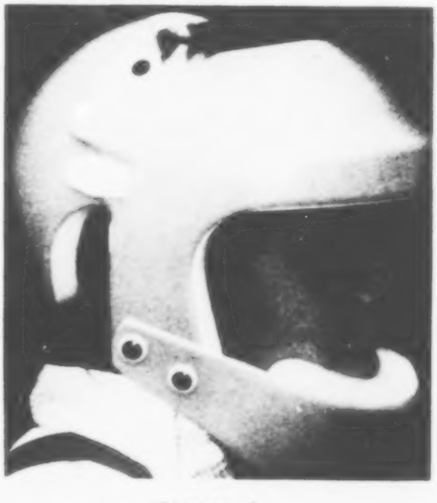


Figure 1

Discussion

The research helmet was found to be an orthotic device which could be readily dispensed in a clinical setting in one appointment. On the average, it required two hours to measure, evaluate and fit the client.

Comments from caregivers suggested that the helmet was well-received. They appreciated the speed with which the helmet was fit, the cosmetic aspects of the helmet, and foremost that it offered the protection needed for their children during the trial period. The extent to which the helmet had met caregiver expectations and its rated overall performance are shown in Figures 2 and 3.

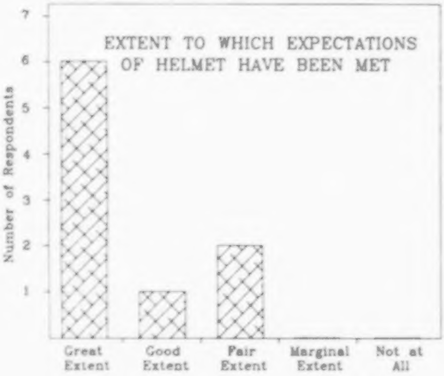


Figure 2

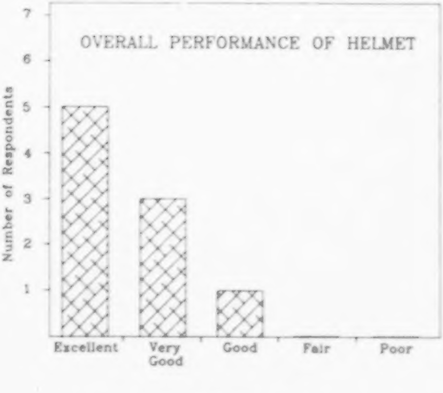


Figure 3

At the follow-up appointments, some adjustments to loosen the chin cup were made as the fit was too snug and caused some discomfort. The helmet appeared to provide the protection required for the children tested, as evidenced by the injury-free service provided. Generally, it was durable, however, longer term study will be necessary to determine the service life of the helmet.

Preparation is underway to commercialize the helmets through Variety Ability Systems Incorporated (VASI). It is envisaged that the helmets will be available in kit form to certified orthotists only after they have taken a training course which instructs them on the proper assembly and fitting procedure.

References

Belbin, G. and Giavedoni, B. (1987). Custom-fitted protective headwear. Journal of the Association of the Association of Children's Prosthetic-Orthotic Clinics, 22(1), 4-7.

Hill, S., Moran, R., Bochmann, D., Milner, M., Singleton D., Belbin, G., & Giavedoni, B.(1987). Development of protective headwear for disabled people. Proceedings of the 10th Annual Conference on Rehabilitation Technology (RESNA) (pp. 213-215). San Jose, CA: RESNA Press.

Canadian Standards Association (1983). Hockey Helmets: CAN3-Z262.1-M83. Canadian Standards Association, Rexdale, Ontario.

Acknowledgements

This project was supported by the National Health Research and Development Programme of Health and Welfare Canada.

We also acknowledge the assistance of CanStar Sports Group in making available their biomechanical test facilities for evaluating the impact performance of the research helmet.

Hugh MacMillan Rehab Ctr
350 Rumsey Road
Toronto, Ontario, Canada
M4G 1R8

P1.8

COMPARISON OF "KEANE" AND "ROTO-REST" KINETIC BEDS

Peter C. Werner, MD †, Eric E. Sabelman, PhD *
†Physical Medicine & Rehabilitation, Santa Clara Valley Medical Center
* Rehabilitation R&D Center, Palo Alto VA Medical Center

ABSTRACT

Acute spinal cord injury (SCI) patients are frequently placed in cervical traction on a kinetic bed, which reduces risk of pressure sores and respiratory or vascular complications by continuous side-to-side tilting. Two types of kinetic bed were compared in clinical use; problems with secure handling of SCI patients were qualitatively documented. The Keane bed was found to have advantages mainly related to convenience of use, but had remediable safety-related deficiencies compared to the RotoRest bed.

BACKGROUND

The purpose of a rotating bed is the reduction of prolonged pressure on any one area of the skin, which induces decubitus ulcers (pressure sores), and improvement in venous circulation, to prevent thrombosis. Acute cervical spinal injury patients have the additional requirement of maintenance of spinal alignment during rotation (typically 60° to either side of vertical [1], so that risk of additional trauma to the spinal cord is minimized. The design problem is one of providing support for the back and sides of the neck and base of the skull so that any applied moment causes change in intervertebral angle lower in the spinal column (C6-C7, C7-T1 or lower) rather than at the level of injury.

Continuous side-to-side tilting may be performed on the Keane (Mediscus Group, Buena Park, CA) [2] or "RotoRest" beds (Kinetic Concepts, Inc., San Antonio, TX). Beneficial effects of kinetic therapy on pulmonary function and venous circulation are cited by Schimmel, *et al.* [3], Green, *et al.* [4] and Milazzo and Resh, [5].

Constancy of traction force and cervical spinal stability during turning on kinetic beds is poorly documented. One experimental study is that of Keane [6], in which an instrumented dummy in traction was turned by experienced practitioners. Meinig, *et al.* [7] found cyclic variation in traction force of 50% during turning, in addition to transient variation with manipulation by attendants. Others [8,9] have made radiographic measurements during turning while in traction, finding neck angular motion of 2 to 9°. In our previous work [10], we measured traction force and head/chest motion in cervical SCI patients on the RotoRest bed at 7.5° head-up inclination, finding that traction varied from 44% to 145% of the nominal 10 lb force.

METHODS

The Spinal Cord Injury Unit at Santa Clara Valley Medical Center has used the RotoRest bed for seven years. While the RotoRest bed has been generally satisfactory, it was decided to clinically evaluate the Keane bed when it became available locally. During the 6-week trial period all eight SCI patients requiring cervical traction were placed on the Keane bed.

RESULTS

Head Support

The available adjustment of the head support parallel to the body axis is 8 inches in the RotoRest bed and only 4 inches in the Keane bed, before the supports fall out of their guide tubes [Figure 1]. Fitting the Keane head supports to some patients requires pulling the support bracket nearly out of the tube. In five instances with three patients a bracket came loose, in one case requiring manual support until the bed could be brought to horizontal. Because of the large adjustment available on RotoRest head supports, similar disconnections have not occurred.

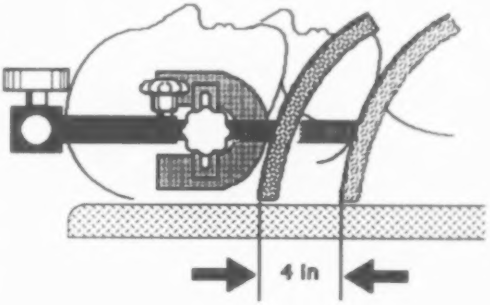


FIGURE 1: Range of head support adjustment - Keane bed

A second problem with the Keane head supports arises from the soft earpieces ($1\frac{3}{4}$ inch highly-collapsible soft open-cell foam). While the patient has Gardner-Wells tongs in place, the knurled knobs of the skull fixation screws protrude about three inches laterally. As the bed turns increasingly to one side, the soft earpiece foam compresses and allows the head to slide laterally downward, with the result that the Gardner-Wells knob runs into the head support tube [Figure 2]. As the bed turns further, the knurled knob slips off the support tube with further sudden lateral head movement and slight head rotation opposite to bed rotation. Because of the metal-to-metal contact and sudden release, there is a loud "clunk" which is disturbing to the patient, especially when sleeping. This phenomenon occurred with two patients during the trial period.

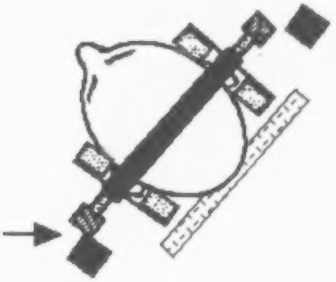


FIGURE 2: Impingement of Gardner- Wells knob on head support tube (arrow)

The RotoRest bed is less subject to this problem because its head support pad consists of a sandwich of $\frac{1}{2}$ inch noncompliant closed-cell polyethylene foam bonded to $\frac{1}{2}$ inch soft open-cell foam. Head movement is much reduced during bed turning because the earpieces are much less compressible.

A third consideration relating to the head supports is that the RotoRest earpiece attachment plates can swivel to adapt to the patient's head shape and to distribute pressure between the zygomatic arch and the mandible [Figure 3- A]. The Keane earpieces cannot be swiveled, and all of the head weight is supported by the zygomatic arches alone during side lying [Figure 3-B].

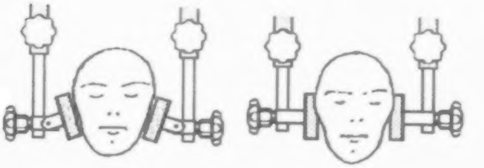


FIGURE 3: Earpiece pressure: A. RotoRest, B. Keane

Thoracic and Pelvic Support

In any rotating bed, if the thoracic and pelvic supports are loose, the trunk will slide back and forth with bed rotation, giving rise to skin breakdown from repeated shearing rather than from perpendicular pressure. Even more seriously, large trunk movements with an immobilized head cause considerable neck motion. The side supports for chest and pelvis must therefore be snug and immovable.

In both beds, the side supports are held in position by cam- type locks bearing against the underside of the platform and are released when the cam levers are in a vertical position [Figure 4]. Note that on the RotoRest bed, the cam is locked in both horizontal positions [A and B in Figure 4]. This is also true for position C on the Keane bed; however, in position D, the lever on the Keane bed gives the illusion that the cam is locked and providing pressure aginst the platform, when it is not and allows the side supports to move freely in their slots. Despite an instruction plate next to the cam mechanism, cams were found to be incorrectly positioned [as in Figure 4-D] in a patient who on the following day developed a black sacral eschar eventuating in a Grade III pressure sore that required several weeks for complete healing.

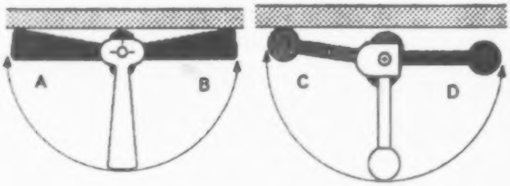


FIGURE 4: Locking lever: 1. RotoRest, 2. Keane

The incidence of superficial Grade I sacral sores, slits and red areas increased during the Keane bed trial period. The number of iliac crest sores increased as well, probably by the process depicted in Figure 5. Because nurses are aware of the problem with insufficient head support adjustment length, they keep the patient placed as far cephalad in the bed as possible. This necessarily pulls the iliac crests against the inner inferior edge of the chest support panels, causing high pressure on the iliac crests during side lying [Figure 5]. As a result, two patients suffered iliac crest skin breakdown and many patients had non-blanching red areas over the iliac crest. Only one iliac crest sore is known to have occurred during previous experience with the RotoRest bed. Iliac crest breakdown is clinically important because it eliminates the use of iliac crest donor bone for surgical fusion of the spine.

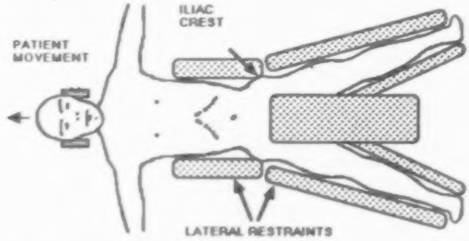


FIGURE 5: Impingement of side restraint on iliac crest - Keane bed

Articulating side panels of the patient support surface under the mattress on the RotoRest bed (absent on the Keane bed) enable the patient's hips and shoulders to be ranged into extension and permit better access to the patient's chest for cardiopulmonary resuscitation when the side panels are folded down. Also, skull fixation screws can be more posteriorly placed during installation of a halo ring because there is more room for the torque screwdriver [Figure 6]; the posterior pins are thus more nearly opposite the frontal screws.

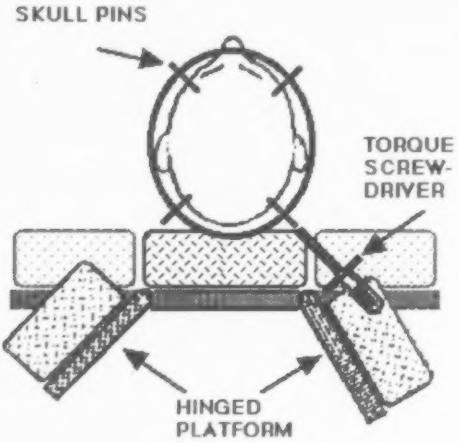


FIGURE 6: Hinged side platforms and halo screw insertion - RotoRest bed

DISCUSSION

With regard to head supports, the twofold difference between Keane and RotoRest adjustments is by far the most important distinction between the two beds, because it relates directly to cervical spine safety. The difference in cam design between the two beds relates both to thoracic spinal stability and to the risk of pressure sore development, and thus is probably the second most important point of design comparison.

There are several areas in which the Keane bed appears to be superior to the RotoRest bed, including:

1. Better overall workmanship.
2. Rotation is easily engaged and disengaged in any position.
3. Rotation angle can be set with pushbuttons.
4. A "no movement" alarm is included.
5. A support bracket for an endotracheal tube is supplied.

The RotoRest bed has the following advantages when compared to the Keane bed:

1. Markedly greater cervical spine safety.
2. Lower likelihood of pressure sore development over sacrum and iliac crests.
3. More trouble-free head support, especially for patients with Gardner-Wells tongs.
4. Opportunity for greater proximal joint range-of-motion maintenance by Physical Therapy.
5. Greater ease of halo ring placement.
6. Lower minimum bed height, permitting patient care by short nurses without need for a footstool.

While each bed has advantages over the other, it seems that the Keane bed's properties relate mainly to convenience of use and improved appearance, while the RotoRest bed has advantages related to greater cervical spine safety, lesser chance of pressure sores and improved patient care and physical therapy. Except for excessive minimum bed height, any shortcomings of the Keane bed are remediable by simple design modifications. As it is, the Keane bed is not yet equivalent to the RotoRest bed with respect to patient safety.

Recognizing the need for better lateral restraint on kinetic beds, the VA has begun a pilot project to investigate active servomechanism control of patient position. It is hypothesized that active control of segmental position, using feedback from sensors that measure deviation of the body from optimum spinal alignment, will be superior to conventional cushions. The test environment consists of simulated body masses on a small-scale bed, which operates with a faster variable rotation cycle than the 8-minute cycle of the actual bed.

Address correspondence to E. Sabelman, m/s 153, Palo Alto VA Hospital, 3801 Miranda Ave., Palo Alto, CA 94304.

REFERENCES

1. Wilmot, C.B., Yoshimura, T., Thomas, E., "Retrospective review of the use of the Rotobed in respirator dependent quadriplegia (C1-C3) 1983-1985", *Continuous Oscillation Therapy: Research & Practical Applications* Green, B.A. & Summer, W.R., eds., (Univ Miami Press), p. 23, 1986.
2. Keane, F.X., "Roto-rest", *Paraplegia*, 7: 254-8, 1966.
3. Schimmel, L., Civetta, J.M. & Kirby, R.R., "A new mechanical method to influence pulmonary perfusion in critically ill patients", *Critical Care Medicine*, **5**: 277-279, 1977.
4. Green, B.A., Green, K.L., Klose, K.J., "Kinetic nursing for acute spinal cord injury patients", *Paraplegia*, **18**: 181-6, 1980.
5. Milazzo, V., Resh, C., "Kinetic nursing- a new approach to the problems of immobilization", *J Neurosurg Nursing*, **14**: 120-124, 1982.
6. Keane, F.X., "Pain and cervical traction variation during manual turning", *Paraplegia*, **15**: 343-8, 1977-78.
7. Meinig, R.P., Leininger, P.A., Heckman, J.D., "Comparison of skeletal traction forces in patients treated in conventional and oscillating hospital beds", *Clin Orthop Rel Res*, **210**: 166-172, 1986.
8. McGuire, R.A., "Comparison of stability provided to the unstable spine using the kinetic therapy table and the Stryker frame", *Continuous Oscillation Therapy: Research & Practical Applications* Green, B.A. & Summer, W.R., eds., (Univ Miami Press), pp. 9-16, 1986.
9. Salciccioli, G.G., Kuric, J., "Cervical stability on the Roto kinetic treatment table", *Proc. 13th Annual Scientific Meeting, American Spinal Injury Association*, pp. 336-7, 1987.
10. E. E. Sabelman, N. K. Kissinger, S. Marble, C.B. Wilmot, "Dynamic Traction Force And Neck Stability On The Kinetic Bed", *RESNA Proc 13th Annual Conference* (Washington, DC June 15-20), paper 17.5, pp. 175-6, 1990.

A Vinyl Vacuum Forming Process For Covering FIP Systems

Nigel Shapcott, David VanNote, George Cook, Carol Kelly, Ted Bogue, Jim Lenker

Therapeutic Positioning Workshop, JN Adam Developmental Center, NY and
the Rehabilitation Technology Service, The University at Buffalo, NY

Abstract

This is paper describes a Vinyl Vacuum Forming technique for covering foam in place seating systems. This technique will transfer to other centers who are using the Dynamic Systems MEDIUM Foam In Place Kit, or other similar systems.

Background

Foam in place (FIP) seating has existed in various forms with varying degrees of popularity for a number of years [O'Leary, 1981]. When properly used, FIP systems can provide an excellent postural support system which evenly distributes loads imposed by seated position.

The foam in place approach is used as the basis for the Pin Dot Products Contour-U System, as well as systems by Pyramid Rehabilitation Canadian Posture and Seating, and Dynamic Systems.

Because of pressures to reduce the cost of purchased components (and also reduce the risk of potentially expensive failures), use of the Dynamic Systems FIP kit has increased in recent years. This low cost system requires local fabrication of a chassis or "shell" to contain the foam during the actual FIP process and provide lateral support to the finished system. The shells are normally constructed of high density polyethylene (ABS) or plywood and then attached to the base unit (typically a wheelchair).

Objective

A limitation with the Dynamic Systems FIP Kit technique, however, has been the lack of a functional, esthetic and cost effective method for covering the finished systems. Various types of covering have been tried or are currently used: custom sewn upholstery, neoprene rubber with nylon material bonded to one side, and lycra applied with adhesive - all of which have disadvantages of cost, appearance and/or function. Vacuum forming of vinyl covers has been used successfully for a number of years, particularly with Bead Seating systems [Hobson, 1983] and with the Contour-U system [Silverman, 1982]. Therefore, a decision was made to investigate the potential of vacuum forming of vinyl covers as a cost effective technique for FIP systems.

Method

The Dynamic Systems FIP kit is traditionally used by mixing the foaming materials and pouring them into a polyethylene bag contained within the wheelchair "shell" on which the client is positioned. The usual provision process for a Dynamic Systems Foaming Kit involves a one piece seat/back system.

In order to allow for Vinyl Vacuum Forming, one must be aware of the constraints imposed by the size of the Vinyl Vacuum Forming Machine itself. These constraints vary from machine to machine and are directly related to the size of vinyl sheet the machine can accommodate (usually around 28" x 32").

For all but the smallest client, covering by Vinyl Vacuum Forming is not possible for a one piece system. A separate seat and back, in most cases, will enable the Vinyl Vacuum Forming process to be carried out successfully. A separate head rest, where appropriate, also reduces the effective size of the back component, simplifying the covering process.

Reinforcement of the shell's sides is necessary to prevent the collapse of the FIP shape. The reinforcement may remain part of the system if desired or may be provided on a temporary basis.

Our method is to remove the completed shell from the wheelchair and utilize it as the means of support for the vacuum forming process. When using the shell as the means of support, though, 3/8" holes must be drilled through the back to allow the vacuum to draw through the FIP insert. Locating holes at the points of the deepest draws has proven helpful.

After the foam has sufficiently cured, the components to be covered are sprayed with 3M77 adhesive and a 1/8" layer of open cell foam is laid onto the surfaces to be covered. This has two purposes. The first is to provide a passage for air to escape during the vacuum forming process, and the second is to help "iron out" any wrinkles that might form during the FIP process.

The vacuum forming process has been carried out with various inexpensive Vinyl

Vacuum Forming machines [Hobson, 1983] [Shapcott, 1983]. We utilized a commercially available "Shop Vac" with an added circuit to control the speed of the motor, which in turn facilitated control of the vacuum. Our strategy has been to use full power momentarily to form a vacuum seal, and then immediately reduce the vacuum to 18-20" of water. This prevents significant deformation of the cushion and expedites the Vinyl Vacuum Forming process to ensure true thermoplastic deformation.

The vacuum is applied for approximately five minutes or until the vinyl cover is cool to the touch. The cushion vinyl is then removed from the Vinyl Vacuum Forming machine for stapling or other finishing methods.

It cannot be stressed strongly enough that the control of temperature during the Vinyl Vacuum Forming process is vital to the success of the operation. A common mistake is to achieve the correct temperature of the vacuum formable material, but to allow the material time to cool below its thermoplastic state. It does not take long for a thin material to cool significantly while in an ambient temperature of 70-75 degrees F. The rate of temperature drop has been measured at an initial 5 degrees F/second (Shaw, 1991), which implies that the temperature of the vinyl would drop as much as 50 degrees F in only 10 seconds.

It is sometimes difficult to perceive this problem because the atmospheric pressure involved in the process will allow the material to stretch elastically to conform to the shape to be covered. Any adhesive used may hold the shape temporarily, but a true thermoplastic forming will not have taken place, and eventually the material will "hammock" as it moves away from the FIP surface.

Precise control of the vacuum is also vital to the success of the Vinyl Vacuum Forming operation. This is particularly true with FIP, where a deformable shape is being covered. We found that the vacuum must be limited to 18-20" of water. This pressure applies loading to the FIP that is of the same order of magnitude as an individual sitting on the cushion. Note that to achieve proper accuracy, calibration should be carried out using a water vacuum gauge.

Results

When all the conditions are controlled as specified, we have found that the slight deformation of the FIP during the Vinyl Vacuum Forming process recovers to give a slight "wrinkling" of the vinyl cover. This wrinkling reduces any hammocking effect of the cover when the weight of a person is on the cushion.

Favorable comments have been received from therapists and care givers, as well as technicians involved in covering. This process provides a functional, durable, esthetic, easy-to-clean cover in a short time and compares favorably to other methods.

Discussion

A caution here is to note that we have not yet checked for any changes in pressure as a result of the covering process. Therefore pressure checks should be carried out to ensure that they are satisfactory for particular clients needs. We will be examining this issue as well as the results of working with different types and densities of FIP Foams.

Technical Information

Materials:
- Naugaform 4000
- Adhesive 3M77
- 1/8"-1/4" open cell foam
- Dynamic Systems Medium FIP Kit

Devices:
- Shop Vac, Model 800C, 12 gallon, 1.5 Hp
- Motor Speed Control - Power Control, #PCA-1020, 8.3 amps, Ohmite.
- Gauge - 30" Water, 1490 A-02L, A strength

Temperature:
300 F (for optimum Naugaform covering)

Vacuum :
20" water (maximum to avoid distortion of the cushion shape)

Acknowledgements

Funding for equipment was provided by JN Adam Developmental Center, Perrysburg, NY.

References

1. O'Leary J., Bretz J., Gallo S., Thibault M., A Rigid Urethane Foam Contour Seat. Proceedings of 4th Annual Conference on Rehabilitation Engineering, Washington, 1981.

2. Hobson D., Heinrich M., Hanks S., Bead Seat Insert Seating System. Proceedings of the 6th Annual Conference on Rehabilitation Engineering, San Diego, 1983.

3. Silverman M., Silverman O., Torossy C., Contour-U, A Custom Total Seating System. Proceedings of 5th Annual Conference on Rehabilitation Engineering, Houston, 1982.

4. Hobson D., Seaton B., Shapcott N., Vinyl Vacuum Forming. Proceedings of the 6th Annual Conference on Rehabilitation Engineering, San Diego, 1983.

5. Shapcott N., Heinrich M., Seaton B., Abraham J., Second Generation Vinyl Vacuum Forming Machine. Proceedings of 2nd International Conference on Rehabilitation Engineering, Ottawa, 1984.

6. Greg Shaw, UTREP, Memphis, TN. Personal communication, 1991.

Nigel Shapcott,
Rehabilitation Technology Service,
515 Kimball Tower,
University at Buffalo,
Buffalo, NY 14214

P1.10

The Customization of an Arm Slot Controller - A Case Study

Elizabeth A. Muik, Roy B. Davis, Cecile Dzielinski, Sue Craffey
Rehabilitation Engineering and Rehabilitation Services
Newington Children Hospital
Newington, Connecticut USA

Abstract:

A highly customized paddle switch array, similar in function to commercially available arm slot controllers for power wheelchairs, was designed and fabricated for use with a Fortress 655. The process of deciding to fabricate a custom device (as opposed to the adaptation of a commercially available device), as well as the specifics of the paddle switch array, will be described through a case example.

Background:

From a rehabilitation engineering perspective, the prescription of adaptive equipment involves the consideration of several options: 1) purchasing a commercially available piece of equipment; 2) modifying a particular commercially available device if extensive adaptations are not required; or 3) designing and fabricating a custom device specific to an individual. These options are listed with respect to their associated priority. That is, in terms of the overall cost of a particular adaptive device, the time associated with partial or full customization typically adds expense to the end product. The probability of the success of a particular device, however, is quite often enhanced by the appropriate utilization of technical customization. This process will be illustrated through the following example.

R.P. is a thirteen year old female with mixed athetoid quadriplegia secondary to a near drowning episode who received a power wheelchair to increase her mobility and independence in school. A wafer switch (#5018; Tash Incorporated, Ontario, Canada) was originally prescribed to control her power wheelchair (Fortress 655; Fortress Scientific, Buffalo, New York) because it was felt that R.P. could best operate her chair using five microswitches with her left hand. However, the wafer board posed several problems: 1) the surface area of each pressure pad was too small; 2) the pressure pads were too close to one another; and 3) the slight indentation of the pressure pads made access difficult because of her limited hand function and strength. Following the use of the wafer board, an arm slot controller (Prentke Romich Company, Wooster, Ohio) was tried because of the larger surface area and higher profile of the switch plates or keys. During her trial period with the arm slot controller, it was found that the accuracy of selecting specific keys increased with R.P.'s arm fully extended and with the slotted board positioned at the most distal end of her arm and in the center of her tray. However, when this was done other problems were realized: 1) R.P. showed difficulty with reaching the pads at the ends of the array; 2) she could not consistently generate the force necessary to activate the keys using her forearm; 3) the dividers between the slots were too high for R.P. to use the keys sequentially; and 4) with her present laptray, it was difficult to secure the arm slot controller to her wheelchair. At this point it was felt that the customization of a new slotted board or the modification of an existing one would be pursued.

Objective:

Since significant modifications were required to make an existing commercially available slotted board functional for R.P., it was decided that a highly customized yet simple paddle switch array could be designed. Our objective then was to provide an array of adequately-sized switch plates or keys in a configuration that was optimal for R.P and which were sensitive enough for her to activate.

Methods:

The physical layout of the custom paddle switch array (Figure 1) was designed according to the range of motion in R.P.'s left arm and the dimensions of her laptray, i.e. extension beyond the width of the tray was not considered because of clearance and safety reasons. The size of the keys (4" x 2" x 1/4") were modelled after those on the commercially available arm slot controller. It was decided that if there was enough space between the keys then dividers (like those on the arm slot controller) would not be necessary, resulting in a very low profile device (Figure 2). To decrease the force available to activate a momentary switch using a switch plate or key, the switch was placed under the most distal end of the switch plate to increase the lever arm of the key. In addition, pieces of low density Sunmate foam were placed in front of the switches as springs to return a key to its original position and low profile switches were purchased to minimize the excursion of the keys required to activate them. With flexibility to arrange the order of the keys, the least used directional function for R.P. (reverse) was wired to the leftmost key because it was occasionally difficult to reach. For mounting, the paddle switch array was designed to slide into a 1" notch along the width of her laptray rim which already existed for a communication board which was no longer in use. This elevated the board 2 1/8" over her laptray thereby minimizing the consumption of her working surface.

Results:

Although R.P. is easily distractible, her use of the paddle switch array has significantly improved over time. Activating any one switch for a long period has been an issue for her because of her athetosis; however, this parameter has improved with practice, along with her accuracy of key selection. The separation between the keys helps her from activating switches simultaneously and also better defines the space around each key. The 4" length of the keys has proven useful in that for quick changes, R.P. can press the direction keys with her arm fully extended but for longer distances, she can relax her arm and rest her hand on the laptray and her fingers on the front portion of the keys. Since the start of the project, R.P. has been prescribed a resting hand splint to reduce her athetoid movements and this further assists with travelling long distances.

Discussion:

This project has illustrated the importance of critical observation and attention to details when prescribing and modifying adaptive equipment, i.e. the effectiveness of a device may sometimes be greatly enhanced by subtle changes to a specific design. In the situation presented here, the commercially available options were evaluated first and found to be inappropriate for R.P. Individual switch pads could have also been arranged on her laptray and connected to the chair controller in such a way that R.P. might have had success in maneuvering her wheelchair, however, consistent placement and increased set-up time might have been of concern. The custom paddle switch array designed for R.P. generates the same output as commercially available arm slot controllers, but with a low profile, different layout of keys, simple construction, ease of attachment, and minimal use of her laptray. Although a significant amount of time was invested into the development of this paddle switch array, subsequent devices of similar design will require substantially less time because the subtleties associated with the customization have already been identified.

Elizabeth A. Muik
Newington Children's Hospital
Rehabilitation Engineering Department
181 East Cedar Street
Newington, CT 06111

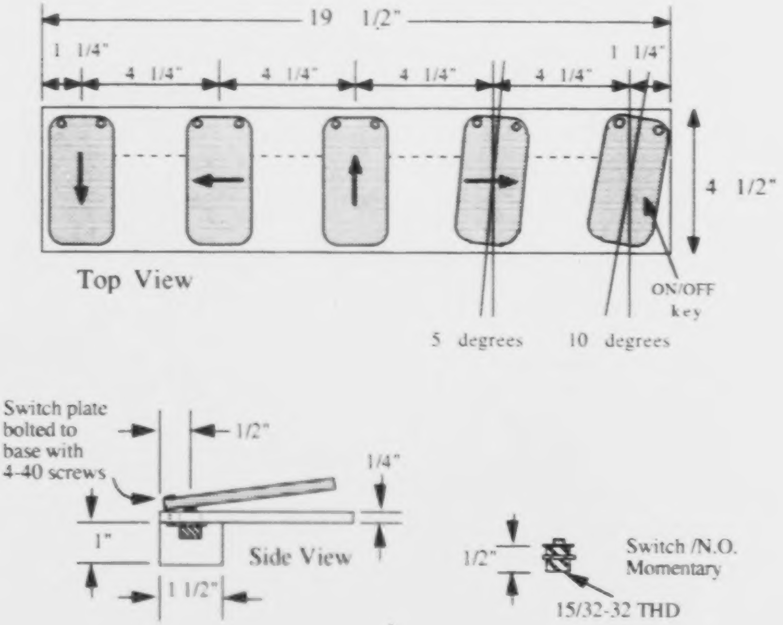


Figure 1. Physical layout of custom paddle switch array.

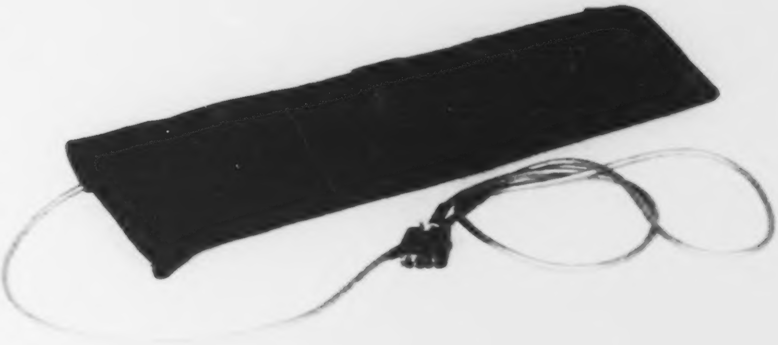


Figure 2. Photograph illustrating the low profile design of the custom paddle switch array.

A BETTER MOUNT FOR LIGHT POINTERS

Debbie Field
Sunny Hill Hospital for Children
Vancouver, B.C. Canada

For some physically disabled individuals, light pointers are a viable means for indicating their choices. However the pointers must be held in a position that maximize their use, and the mount must be acceptable to the individual and significant others (eg. parents, family, friends, teachers, co-workers). A headmount was designed to achieve stability of the light beam, comfort and aesthetics.

Introduction:
Using one's hands is the most preferred and accepted means for individuals to access augmentative communication aids. However there is a segment of the population who because of a physical disability cannot use their hands, or have significant limitations of their hand/arm movements. For these individuals other body sites are often investigated for maximizing independent control. Head and neck movements are for some the easiest to execute, the most consistent, or offer the finest degree of motor control (Lee and Thomas, 1990; Fishman, 1987).

Light pointers are suitable for some of these individuals because they provide direct selection and visual feedback both for the user and the communication partner(s) (Faux, 1989, Fishman, 1987, Charlebois, 1985). They allow the user to access technical and non-technical augmentative communication systems as well as to indicate desired objects in the environment (Faux, 1989; Eriksson et al., 1987, Wright & Nomura, 1985). Light pointers are small and lightweight. The challenge for the clinician has been to provide a mount that holds the light pointer securely in a useful position.

Several manufacturers have addressed this challenge. Adaptive Communication Systems Inc. and Prentke Romich Co. produce optical pointers with headmounts for use with their LED communication aids. Crestwood Co. and Jim's Instrument Manufacturing Inc. produce light pointers with headmounts for use as "nontechnical" pointing devices. Zygo Industries Inc., and Maddak Inc., are among manufacturers that produce headpointers that utilize a headmount that one may adapt to hold a light pointer. Clinicians have a choice of using commercially available headmounts, headmounts that are individually adapted, or custom made ones. Some have mounted light pointers to eye glasses or helmets as alternative headmounts.

Statement of Problem:
There are several problems with commercially available headmounts for light pointers. Although all manufacturers provide adjustability for fitting different sized heads, our experience has been that a secure but comfortable fit is elusive. This is influenced by the variety of head shapes as well as the properties of the materials used (more flexible materials that fit better often don't have the strength to hold the light securely). A comfortable but secure fit is more difficult to achieve with children (although some companies make child sizes). Other problems include instability at the light / headmount junction and the inability to keep the lightbeam positioned at the most appropriate viewing angle. This often creates great frustration in the user as they try to target the light on desired objects or areas.

For some individuals the look of the headmount is very much the issue. Most have straps that encompass the head's circumference, some have straps over the crown of the head and/or under the chin. The mounts with better stability usually have wider bands which are more noticeable. Some have obtrusive knobs for size or angle adjustments. Most are fabricated out of plastic, or fabric with limited or no colour choices.

A BETTER MOUNT FOR LIGHT POINTERS

Rationale:
For some physically disabled individuals, light pointers are a viable means for indicating their choices. However the pointers must be held in a position that maximize their use, and the mount must be acceptable to the individual and significant others (eg. parents, family, friends, teachers, co-workers). None of the commercially available headmounts met all the criteria specified by our rehabilitation technology specialists and users.

Design:

Design Criteria
A new headmount to hold the lightpointer was pursued in order to meet the identified criteria:

- the fit must hold the light securely on the head
- the fit must be comfortable (for 3 hours or more)
- it must be easy to put and take off
- it must be adjustable after initial fitting (for both head size and viewing angle)
- it must be pleasing to the user and their significant others
- it must be easily obtainable(within 2 days of identifying need)
- it must be of reasonable cost (less than $75.00)

Final Design
The design was a custom molded headband fabricated of Aquaplast (3mm thickness). It consisted of a band going around the circumference of the head and another band going over the top of the head (in line with the temples). This was to provide stability. The light pointer (most commonly used was the ACS Light Pointer) was held on to the headmount by another band stretched snugly over it. This allowed the light to be easily slid out of the mount (for repairs, or protection when not in use). A wedge of the same material was placed under the light, attached to the headband. This held the lightbeam at the most suitable viewing angle. (see Fig. 1).

Development:
The development of the headmount evolved after several prototypes were evaluated clinically. The initial design had the band as one continuous piece of Sansplint. Although the fit was secure it was difficult to put on and take off, it was uncomfortable, unpleasing to the eye, and the band stretched over time. Several different materials were tried to improve fit, aesthetics, and comfort, including velofoam, leather, platezote and other low temperature thermoplastics. Aquaplast worked best, along with changing the design to an overlapped piece attached by velcro. Sticky backed foam placed inside the bands also improved comfort and fit.

Evaluation:
There has been 19 headmounts constructed and used clinically. All were used in the assessment, and most have continued to be used upon receipt of the individual's own equipment. Seven were prototypes and have now been replaced with the final design. The longest period of use has been one year. The twelve now in use have met all the criteria; the users and caregivers are pleased with their performance.

Discussion:
The use of the headmounts have met with acceptance and success. One of the reasons for this is the user is involved in choosing the colours of their bands (blues, pinks, white, or neon yellow), and they later personalize them with stickers, etc. Some parents have made covers that go over the headmount that are coordinated with different outfits. The fit and comfort enable the user to direct the light easily and accurately for many activities throughout the day. Adjustments in fit and lightbeam angle are easily accomplished with a heatgun or hairdryer.

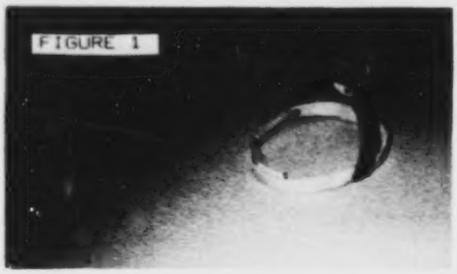


FIGURE 1

BEST COPY AVAILABLE

There are two problems that require further consideration. One is the initial fabrication time. It takes two hours, because each piece is fabricated on the spot. This is often difficult with younger children. Also some do not tolerate the fitting of the bands on their heads. This may because they are tactilely sensitive or because it takes several minutes for the material to harden, and they have difficulty keeping their heads still. Having a stock pile of ready made pieces would help alleviate these problems as would having sample headmounts for parents, friends, toy dolls etc.

Acknowledgements:
Susan Blockberger and Marion Sollazzo of the Communication Disorders Department at Sunny Hill Hospital for Children.

References:

Charlebois Marois, C., Everybody s technology a sharing of ideas in augmentative communication. Montreal: Charlecoms, p 61, 1985.

Eriksson, B.M., Gawell, A. & Munthe, K., Activities using headsticks and optical pointers a description of methods. Stockholm: Handikappinstitutet, pp 4-6, 1987.

Faux, C., Developing effective communication for the physically handicapped child. Tucson: Therapy Skill Builders, pp 6-7, 1989.

Fishman, I. Electronic communication aids selection and use. Boston: College Hill Publishers, pp 62-64, 1987.

Lee, K. & Thomas, D.J., Control of computer-based technology for people with physical disabilities an assessment tool. Toronto: University of Toronto Press, pp 98-99, 1990.

Wright, C. & Nomura, M., From toys to computers access for the physically disabled child. San Jose: Wright, pp 119, 131, 1985.

Adaptive Communication Systems (ACS) Inc.
ACS Light Pointer
PO Box 12440, Pittsburgh PN. 15231

Crestwood Co.
Talking Beam
6625 N Sidney Place, Milwaukee WI 53209

Jim's Instrument Manufacturing Inc.
PO Box 5157, Coralville,IA 52241

Maddak Inc.
Adjustable Headstick/Pointer
Pequannock NJ. 07440-1993

Prentke Romich Co.
Viewpoint Optical Indicator (VOI-6)
1022 Heyl Rd.
Wooster OH. 44691

Zygo Inc.
AD-1 Headpointer
PO BOX 1008, Portland OR. 97207

Debbie Field
Sunnyhill Hospital for Children
3644 Slocan Street
Vancouver, B.C.,
Canada
V5M 3E8

P2.2

ADAPTING THE "HOPKINS SPEAKING VALVE" FOR USE WITH A SHILEY CANNULA

Joseph J. French, John Kummell, and Arthur A. Siebens, M.D.
Division of Rehabilitation Medicine
The Johns Hopkins University

ABSTRACT

The Johns Hopkins speaking valve is a simple ball valve that allows inspiration through the tracheostomy cannula and expiration through the larynx. It was designed for use on a Jackson metal inner cannula. This paper describes its adaptation to a Shiley plastic outer cannula. Flow characteristics of the valve are presented in graphic form. The relative advantages and disadvantages of this valve are compared to a commercially available flapper valve.

BACKGROUND

The Johns Hopkins speaking valve was presented at the ACRM and AAPM&R joint meeting in Boston in 1984 (1). It is a simple one-way ball valve. In Fig. 1 it is shown clipped to a Jackson #6 low profile metal inner cannula. Its operation is shown schematically in Fig. 2. Fig. 2-A shows the valve at rest. When the patient inhales (Fig. 2-B) the ball is forced back out of the port allowing air to enter freely through the port. The ball is stopped from entering the cannula by the wire stop. On expiration (Fig. 2-C) the air is forced to flow through the larynx allowing speech. The port was designed to be off center in order to allow the ball to roll into the port rather than jump into it as with a concentric port. This reduces the pressure necessary to close the valve. For proper operation, the port must be in the 6 o'clock position as shown in Fig. 1.

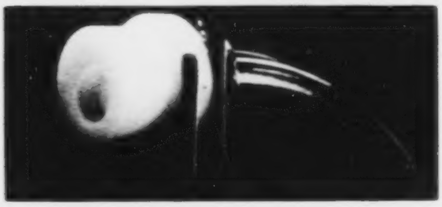


Figure 1.

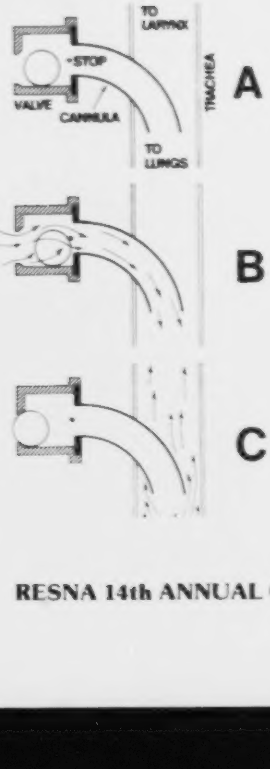


Figure 2.

Fig. 3 shows the flow versus pressure relationship at normal flow rates when the valve is connected to a #6 Jackson metal inner cannula. Both inspiration (negative quadrant) and expiration (positive quadrant) are shown. The pressure required to close the valve is approximately 0.5 cm. of water. Because closure happens very quickly, very little air escapes at the beginning of expiration. The valve will remain closed until the pressure drops to approximately 0.3 cm. of water.

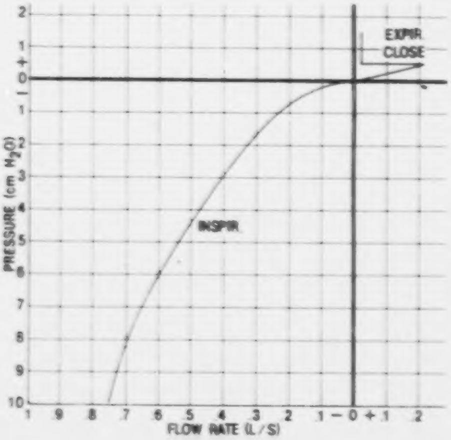


Figure 3.

The valve is sensitive to the position of the patient such that closing pressure becomes greater as the patient's angle of recline is increased. Sensitivity to reclining is not hazardous, for the valve will simply remain in the open position. This valve is recommended primarily for patients who are ambulatory or sitting up in bed or wheelchair.

PROBLEM

The Johns Hopkins speaking valve as originally described was designed to be used with a Jackson metal low profile inner cannula. As shown in Fig. 1 it was attached to the inner cannula by a metal clip. At that time, most of our tracheotomized patients used the Jackson cannula. On the rare occasions that one of the patients had to use a plastic cannula the valve had to be juryrigged to fit it. Although various coupling methods were employed, all required the use of heat shrinkable tubing. Unfortunately, the heat necessary to shrink the tubing was also sufficient to soften or melt the plastic valve and cannula. Moreover, a tight seal between tubing, valve and cannula was difficult to achieve and dead spaces were inaccessible for cleaning. These problems became increasingly pressing as the use of plastic cannulae, such as the Shiley twist lock type, became more common.

RATIONALE

A simple method of connecting the valve to the cannula without the use of heat shrinkable tubing was sought. Modifying the clip and body design of the valve to fit the Shiley low profile inner cannula would have involved major design changes. There was also the possibility that the clip could interfere with the ease of manipulating the inner cannula for such purposes as suctioning. Our search for an adapter that could be easily disconnected from and reconnected to the valve and allow thorough cleaning of both the valve and the adapter led to the following.

DESIGN

Several years ago Shiley introduced a one-piece plastic decannulation plug (Fig. 4). With very little modification, this plug can be converted into an ideal adapter for fitting the valve to the cannula. This approach also required a few minor changes in the design of the valve and the elimination of the clip.

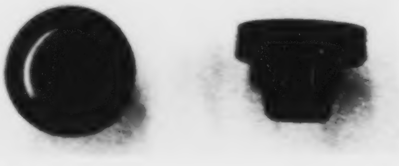


Figure 4.

As shown in Fig. 5 the only valve changes are to (A) eliminate the socket into which the Jackson cannula was seated, (B) reduce the flange diameter, and (C) cut the sharp edge of the flange to a radius that matches the radius of the plug recess.. The only plug changes are to drill (D) a hole through the plug seal and (E) two holes through the plug flange to match up with the holes in the valve flange. The same force fit pin that holds the ball in place also fixes the valve to the adapter. The positions of the holes are critical, i.e., they must be exactly horizontal when the adapter is seated in the inner cannula. This assures that the valve is in its optimal position. A special drill jig was designed and constructed for drilling and matching.

The size of the aperture through the plug seal will vary with the plug size that in turn is determined by the size of the inner cannula. This aperture should be approximately the same diameter as the inside diameter of the inner cannula.

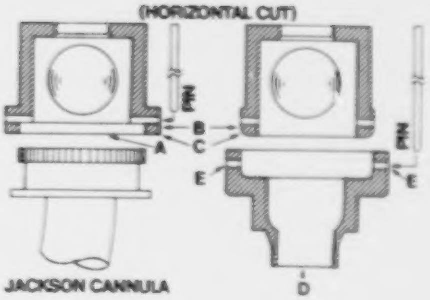


Figure 5.

DEVELOPMENT

The valve-adapter set (Fig. 6, top left) can be disassembled for cleaning purposes then reassembled. This requires the use of two tools: a pin (having a smaller diameter than the retaining pin) that is used to push the retaining pin out of the valve-adapter set and a pair of small long-nose pliers to grasp the push pin. For reassembly, the holes in the adapter must be lined up with the holes in the valve. The pin is then forced all the way into the holes using the pliers. Unfortunately, this procedure may be beyond the capabilities of most patient care providers.

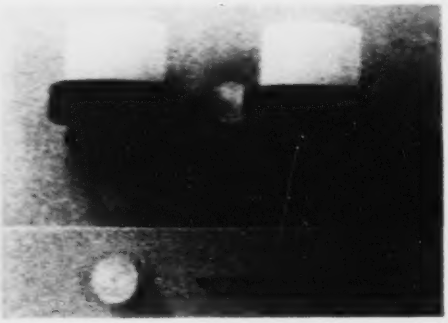


Figure 6.

By modifying the retaining pin (Fig. 6, bottom right) the valve-adapter set can be assembled and disassembled without the use of tools. The pin is made narrower, allowing it to be slipped rather than forced into the holes. One end is formed in the shape of a triangle. This triangle acts as both a handle aiding in assembly and disassembly and as a retainer for that end of the pin. The pin is also made longer allowing the other end to be held by a clip (Fig. 6, bottom left). This clip is actually a "clutch" used for retaining pierced ear earrings. The assembled unit is shown in Fig. 6, top right. Some degree of dexterity is still required but we believe that most people can learn the procedure.

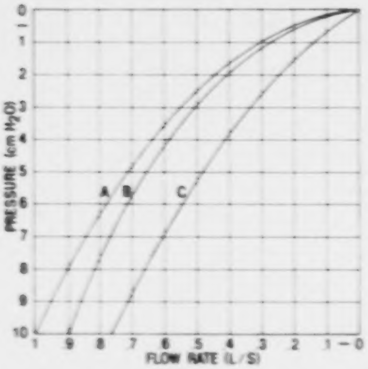


Figure 7.

EVALUATION

The adapted valve is no more difficult to connect to the outer cannula than the regular low-profile inner cannula. Connection can be done by patients who have good dexterity and are cognitively intact.

Fig. 7 (A) shows the inspiratory flow characteristics of a #6 Shiley plastic inner cannula without a valve. Fig. 7 (B) shows the characteristics of the modified Hopkins valve installed in place of the inner cannula. As can be seen, the resistances are comparable.

Because the valved system obviates the use of an inner cannula, there may be concern that keeping the outer cannula free of secretions will be more difficult. This is unlikely to be the case with most patients since the valve prevents air flow into the outer cannula during expiration.

Table 1.

CRITERION	PASSY-MUIR	HOPKINS
Position Sensitive	No	Yes
Closing Pressure	0 cm H_2O	0.5 cm H_2O
Inspiratory Resistance	Higher Fig. 7(C)	Lower Fig. 7(B)
Dimensions	D = 0.9" L = 0.7"	D = 0.6" L = 0.5"
Concealable	Harder	Easier
Self-Apply	Yes (Easier)	Yes (Harder)
Cleaning	Harder	Easier

DISCUSSION

When the Hopkins valve was originally presented, we were unaware of any commercially available alternative. Since that time, at least one flapper type of valve, Passy-Muir (2), has become widely available. When this valve is installed on a #6 Shiley inner cannula, the inspiratory flow characteristics are as shown in Fig 7 (C). There are advantages and disadvantages of these valves, either of which, when properly used, will restore expiratory air flow through the larynx in patients with tracheotomies. Table 1 summarizes the comparison of these two valves.

It is apparent (Table 1) that the Hopkins valve has its greatest advantage for patients that are mobile (either wheelchair or ambulatory) and wish to conceal their valve. The flapper valve has its greatest advantage when used by patients who are bed-ridden, usually in the supine position, and who are less concerned with concealment of the valve.

REFERENCES

1. French, J; Siebens, A; Kummel, J; Kirby, N; and Eisele J. Preserving Communication and Airway Clearance in Tracheostomized Children and Adults. Arch Phys Med Rehabil 65:651, 1984.

2. Passy and Passy, Inc., 4521 Campus Drive, Suite 273, Irvine, CA 92715.

Joseph J. French
The Johns Hopkins University
Division of Rehabilitation Medicine
5601 Loch Raven Boulevard
Baltimore, MD 21239

P2.3

The Future of Augmentative Communications:

A Conceptual Framework for Consumer Empowerment: A Consumer's Perspective

Mick Joyce
Independent Consultant
Madison, WI

ABSTRACT

The author, an active user of an augmentative communication system for seven years, states that much consumer involvement is vital for any new technology. This is especially true of augmentative communications. To continue to grow, ensure quality and develop practical product lines, the industry must have active consumerism. Problems in organization arise because the user population is very diverse in physical and cognitive abilities. Other barriers include geographical sparsity of users, transportation and communication in a 'normal' way. Considering all barriers, this paper suggests ways to link consumers and providers together as team members. The implications of such linkages are increased political and economic power as well as an improvement in the quality of products and services. The author draws from his personal experience as an augmentative communications user. Also, he uses micro-economics, political science, and social change theory in discussing problems and suggestions.

BACKGROUND

As anyone can see, I have a difficult time talking and making my speech understood. This is especially true in groups where I tighten up and my muscles don't do the things I want. At the age of thirty-four, I was introduced to my first augmentative system, a small laptop computer with a voice synthesizer. As a part of a small demonstration project, I got a head start.

Voice synthesizers were not yet "accepted medical treatment." There were only three or four on the market. They were very expensive ($4,000). There was no warranty on the equipment. Frequent breakdowns were the rule, not the exception. One man in the whole United States could fix the voice synthesizer, its creator. The creator had much other work to do. So sometimes my equipment got set aside for many days.

Since those days of yester year, we have progressed a bit. In our state (Wisconsin), Medical Assistance will buy at least one system. More people are obtaining the equipment they need. There are about twelve companies that make voice synthesizers. The prices of many systems have gone down. I just received my new synthesizer two months ago, so I can't tell how much it needs repair. It has a ninety day warranty. Most main-line electronic equipment bought in the same price range has a year warranty. I assume that warranties and other support services cost firms a "pretty penny." Yet, because of competition, the service is provided.

Because I was purchasing voice synthesizer myself without third-party help, I asked about installment plans. No such plans were available. In the mainstream, local electronic dealers offer "easy-payment plans" because they increase sales. Knowing that some people won't pay, these companies write off a certain percent of sales as "bad dept expense."

With my experience in equipment breakdowns, I naturally asked about service. I learned that my new voice synthesizer would have to be sent to a far away city to be fixed. Common sense tells me that it would be a week at the shortest before I'd get the equipment back. With earlier versions of the product, report frequent break-downs with long delays in returning the equipment to the user. I am hoping that this new version of the voice synthesizer will have some "bugs" out.

Space and time limitations prohibit me from detailing similar experiences I had with special software, cables and the main computers. Welcome improvements will continue to be made as more people join us as America ages. Equipment for augmentative communication will follow general computer trends and become lighter and more portable. Natural competition will force many small companies out of business, leaving a few larger ones. These larger organizations, with more resources, should be able to provide mainline services.

Yet, before this happens the consumer should have the opportunity of empowerment. A healthy, competitive industry with quality products and support services is dependent on informed consumers empowered with political and economic strength. It should, therefore, be in the best interest of professional and manufacturer to aid in this process.

STATEMENT OF THE PROBLEM

The problem is how we as professionals, industry representatives, and enlightened consumers can provide the opportunity for other consumers to be empowered in such a manner to give us maximum political and economic power.

This problem is magnified by because augmentative communication users are usually (1) at the bottom of the social and political scales, (2) are of diverse physical and cognitive abilities, (3) have different communications needs and augmentative systems and (4) have diverse interest. Also, these people have more traditional barriers to forming effective groups. Transportation is a real 'hassle.' Telephone conversations are difficult for most augmentative users. Geographic sparsity of the user population makes it hard to share information and gives the augmentative system user a sense of isolation. Finally, some consumers barely have enough economic resources to put food on the table, much less travel long distances to gather.

APPROACH

I have little in the area of concrete solutions on how to solve the problems I face daily. Most likely, the first step is to recognize they exist. Sensitivity is a key element to political harmony. Those of you who are not in wheelchairs should spend a day or a week in one, perform your job from a chair, and see how people react. While you are on this awareness trip don't forgot to ride the special para-transit system, the one designed for your needs. If you are lucky enough to obtain an augmentative communication that works, try turning it off for a while and communicating with something other than your mouth. That's when real awareness begins.

Information is power. So we should share as much information in as many ways as we know how. Developing new ways to share information would also be helpful. Telephones, message relay systems, computer bulletin boards, magazines, and alike could all be used in the most creative ways possible to share information.

Finally, money is power. Sometimes it buys information, awareness and other things. We should think of new ways to get money into the hands of consumers and make things cost less. Whether through government entitlement, training programs, or hiring people with disabilities to operate their programs, any or all methods will be effective in increasing their utility.

IMPLICATIONS

If this common sense approach is followed, the implications are clear. It would give the augmentative communication user more power and put them at more of a parity levels with professionals. This would make them be more of a stakeholder in the effort to produce a more accessible product line. Consumers of augmentative communication systems would most likely feel more responsibility for their systems and would stop blaming professionals for all their woes.

Professionals would have to give up some power and authority. They would become more of a team player. They would have to take more risk. They would not, however, take all the heat for mistakes made. Manufacturers of augmentative system would have to make better products, at reduced cost and less profit margins. This will force some out of business in the heat of competition.

DISCUSSION

Space limitations permit only a brief discussion, here. This idea of consumer empowerment, admittedly, is a 'grand scheme.' Although most of it will become true in time, this presentation is designed to stimulate ideas and cause listener/reader to think and form new visions. The word 'consumer,' here, is meant in the broadest sense. For there is power in numbers and excluding anyone that wants to be included would be, indeed, disadvantageous.

Mick Joyce
Independent Consultant
4 N. Allen Street
Madison, WI 53705

A REMOTE-CONTROLLED COMMUNICATION DEVICE FOR SIMPLE CLINICAL, CLASSROOM AND HOME APPLICATIONS

Carol R. Suddath, Neal F. Vittitoe and Bernard P. Fleming
Department of Special Education
University of Kentucky
Lexington, KY

Abstract

In order for a person with limited motor control and minimal speech to indicate a selection from an array of choices, a simple communication device was designed and fabricated. The device is user controlled by a single switch through a radio link interface to a scanning circuit controlling a set of light-emitting diodes (LEDs). The system allows individual LEDs to be attached to pictures/objects in the environment. The scanning circuit may operate in either direct selection or sequential scanning mode. This device meets the need for a simple, flexible and effective communication system for many applications which arise in the clinic, classroom and home.

Background

Many augmentative communication aids possess sophisticated features which may inhibit their usefulness in some situations. Many applications, whether for testing, instruction or recreation make minimal demands on the sophisticated, programmable features of these aids. Flexibility and simplicity are key elements of a total communication system for any individual (Blackstone, 1986; Burkhardt, 1988). Two specific activities which require flexibility and simplicity are: (1) multiple choice standard testing formats to assess a nonspeaking, severely and profoundly handicapped student, (2) participation in various classroom activities that require the student to discriminate between and make reference to selected stimuli presented simultaneously. In both instances, sophisticated communication devices could be programmed to have the student convey specific information, but the time and effort required for this individualized programming may be difficult to justify. Furthermore, other response modes (e.g., eye gaze, or poorly controlled pointing) leave too much interpretation to the examiner or teacher. For example, the examiner may ask the student which figure represents a fish on a four-part multiple choice test as schematically illustrated in Figure 1. The examiner assumes that eye focus or pointing dwell time is an accurate indication of the intended response of the student. Alternatively, the examiner may point to each item, waiting for a sign of confirmation or rejection from the student. In both instances, the communication receiver must assume responsibility for interpreting the communication attempt of the student. These approaches may prove to be both time-consuming and prone to error.

Rationale

Students frequently need to be able to indicate their choice from an array of items. Students who are physically unable to indicate their choice by conventional pointing or verbal directions need a means whereby they can independently express their choices. There are many commercially available remote-controlled communication aids: rotary scanners, row-column scanners and directed scanning devices. However, in a review of product catalogs for augmentative communication aids and a search of a product database (Adaptive Device Locator System, Academic Software, 1990), no remote-controlled scanning aid could be found that allows placement of separate LEDs at discrete locations in the environment for applications such as a multiple choice tasks.

Design and Development

The design of this communication aid is similar to that of many other simple scanning devices (Webster et al., 1985, p. 249). Figure 1 shows a block diagram of the system. The student controls the device by use of a single momentary switch. The switch connects directly to the radio transmitter module through a standard 3.5mm phone plug/jack to allow choice of different switch configurations. Switch closure therefore produces activation of the radio transmitter. Detection of a signal by the radio receiver controls the function of the scanning circuit. The scanning system consists of a series circuit containing a flip-flop, counter and decoder. A toggle switch is used to set one of the two modes of operation for the scanning circuit: (1) direct selection, or (2) linear sequential scanning. In the direct selection mode, each switch closure produces an advance to the next LED in the sequence. In scanning mode, the LEDs are scanned in sequence with an adjustable selection time (1-6 sec) for switch closure. After switch closure for a selection, a subsequent closure causes the scanning to begin over again with the first LED in the sequence. A distinguishing feature of this device is the use of separate LEDs which can be placed on, or attached to, most horizontal and vertical surfaces. This feature allows the device to be customized for many different applications. LEDs of different sizes, color and brightness can be interchanged. The LEDs are connected to the scanning circuit by short wires. Although this circuit is designed for use with four diodes, it may be modified for use with other numbers of LEDs. The radio transmitter module, receiver and scanning circuits are all battery operated.

Discussion

The straightforward operation and customizing features makes the communication device described in this abstract a valuable aid in many different situations. The features which distinguish this device from many other aids are: (1) elimination of complicated setup and programming which provides ease of use for both the student and the teacher, (2) the use of switch-activated, radio-linked control from the user to the device which eliminates bulky wires and enhances reliability, (3) the use of separate LEDs to mark the choices on individual objects in the environment which allows many different custom applications, and (4) low cost of construction.

Acknowledgement of support: Funding for research was provided by a grant from the Kentucky Assistive Technology Service (KATS) Network.

References

1. Blackstone, S.W. (ed.) Augmentative Communication: An Introduction. ASHA, Rockville, MD. 1986.
2. Burkhardt, L. Using Computers and Speech Synthesis to Facilitate Communicative interaction with Young and/or Severely Handicapped Children. 1988.
3. Adaptive Device Locator System. Academic Software. Lexington, Kentucky. 1990.
4. Webster, J.L., A.M. Cook, W.J. Tompkins and G.C. Vanderheiden (eds). Electronic Devices for Rehabilitation. Wiley, New York. 1985.

Bernard Fleming
Dept. of Special Education
University of Kentucky
229 Taylor Bldg.
Lexington, KY 40506-0001

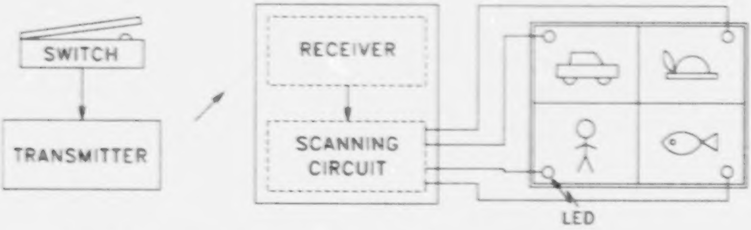


FIGURE 1. REMOTE-CONTROLLED COMMUNICATION DEVICE

Eyegaze And Headpointing Technology For Children And Adults With Mental Retardation

Carrie Brown, Ph.D. - Bioengineering Program, Association for Retarded Citizens of the U.S., Arlington, TX
John R. Kostraba, E.E. - Kostraba Engineering Associates, Denver, CO
Al Cavalier, Ph.D. - University of Delaware, Newark, DE
Catherine Wyatt - Bioengineering Program, Association for Retarded Citizens of the U.S., Arlington, TX

Abstract

In the rehabilitation and educational technology arenas, recent development and use of eyegaze/ headpointing technology has been almost exclusively for individuals with severe physical disabilities, but who do not have cognitive limitations. Consequently, researchers in this project embarked upon a three year study to investigate what issues must be addressed to modifying an existing eyegaze/ headpointing system to accommodate the cognitive and physical needs of people with mental retardation. Although an arduous research project, findings indicate that with continued study, strategic design, attention to cognitive and learning issues, and carefully designed and implemented training strategies, people with mental retardation can benefit from eyegaze/headpointing technology development.

Background

There are more than two million children and adults in the United States whose physical and/or mental impairments are so severe that they are unable to communicate with other persons or interact and learn from their environment in an effective manner (Bricker & Filler, 1985)(1). Disabilities of this degree impact people with cerebral palsy, paralysis, spina bifida, mental retardation, and cardiovascular disease/stroke, and severely limit their ability for independent living, effective education, and productive employment. In recent years, researchers have begun to address these serious needs for freedom of choice, communication and environmental control in more creative ways by developing communication and environmental control system using eyegaze/ headpointing technology (Brown, 1989)(2).

There are two main reasons for employing eyegaze-based and headtracking communication and environmental control aids over more conventional body movement-based aids. First, a large portion of the population of individuals who are severely handicapped (those who are severely spastic and paralytic) do not have any other reliably controllable body movements. Second, even among those people with other reliable body movements, headtracking and especially the eye's response time (20-30 milliseconds) (Tello, 1988)(10) are much more rapid and less fatiguing. Rapidity and ease of constructing a message are typically the determining factors between a person voluntarily using a communication aid and using it only when required to do so. The minimal expenditure of effort that eyegaze head movement entail and the high speed of use that they offer a person makes them tremendously promising for applications to people with severe handicaps.

While eyegaze technology was initially developed for military and clinical applications, since 1976 several researchers have conducted pilot projects on its potential to circumvent the problems associated with other technology approaches for people who are severely disabled (Demasco & Fould, 1982(3); Friedman, Kiliany, Dzmura, & Anderson, 1981(4); King, 1984(5); Rosen, Drinker & Dalrymple, 1976(6); Schneider, 1982(7); Sutter, 1983)(9). This experimental research has been done only with severely motorically-impaired persons and the researchers agree that there is a need for a more concerted and diligent effort to further this body of knowledge (Smith, Christiaansen, Borden, Lindberg, Gunderson, & Vanderheiden, 1989)(8).

Statement of the Problem

This research was devoted to answering fundamental questions about what features are needed, which currently are not available, in eyegaze/headpointing assistive technology for children and adults with severe mental retardation and severe physical impairments. The project designed, developed and tested the eyegaze and headtracking prototype hardware and software based on proven educational and training theory of people with mental retardation. A concurrent strategy was the design and implementation of specific training procedures to use with the subjects.

Rationale

Certain attributes were needed in an effective eyegaze/headpointing system for people with mental retardation. Therefore, a Sentient Systems Technologies' Eyetyper was modified and enhanced into a new prototype/device so that: it has an improved ability to accurately recognize where the user is looking; spoken output is digitally recorded for natural sounding speech; the speech output can be stored on a computer and then transferred back to the device, thus multiple speech outputs can be saved and recalled at will; there is an increase in the display for the number of choices which can be displayed; it has the ability to control up to 256 electrical appliances in the environment; it collects data for each user as s/he interacts with the device for research and tracking purposes; the software is modified so that a single device can be selectable not only for eyegaze but also for headpointing; it is interfaced with a computer for system software upload and download which allows for individualized configuration of the system from one user to the other; and, it is completely portable.

Design

The eyegaze/headpointing communication and environmental control system consists of three major components: the display, the system controller, and the environmental control unit (ECU). A personal computer (PC) is used in order to take advantage of the low cost mass storage and printing devices available through the computer.

The display unit is mounted in front of the user with an adjustable mounting arm. Within the display panel is a modified EyeTyper 300 which serves as a slave sensor and provides user eyegaze/headpointing direction information to the system controller via a serial communications link. The display consists of a panel of eight light emitting diodes (LEDs) arranged in a square around the eyegaze sensor aperture in the center of the display. Photographs, text or symbols can be manually fixed around each LED. An audio speech output amplifier (and speaker) presents speech output selections. Spoken output is presented from the display panel in close proximity to the user so that a strong association develops between the user selection and the audio message. A video signal circuit uses data from the EyeTyper to generate a video image on an external monitor of the user's face as it is 'seen' by the EyeTyper. This image is used by the clinician/supervisor to optimally position the user in front of the eyegaze sensor and to make certain that there are no anomalies in the environment which interfere with the sensor's performance.

The system controller is a custom designed and built computer which controls the operation of the communication system using a programmable Guide. The Guide allows a clinician or supervisor to specify the operating mode and to define the ECU function, if any, of each possible user selection. The PC is used to manage and communicate the Guide to the system controller via a serial communications interface. Speech is digitally recorded with the system controller either directly, by using a microphone interface, or by using messages which have previously been stored on the PC. During system operation, the system controller receives, processes, and stores data from the slave eyegaze sensor. Depending on the programming of the Guide, the system controller may: replay a digitally recorded word or phrase, and/or initiate some action via the ECU. The device is also a data logger for use during clinical research. It stores all information describing user performance so that it may be downloaded to the PC for storage and clinical evaluation.

The environmental control unit (ECU) is an X-10 Powerhouse which is interfaced to the system controller via a serial communication link. The system controller initiates commands to the X-10 which causes the desired action of a device turning on or off in the user's environment.

Development

The eyegaze/headpointing prototype took 18 months for development with continual clinical alpha testing and feedback. The operation of the eyegaze/headpointing communication system can be effectively presented as four discrete steps: setup using the PC, user calibration, user communication, and data evaluation. The first two steps configure the communication aid and the last step allows data for research or monitoring of the progress of the user. Calibration is necessary using the eyegaze sensing technology of the EyeTyper. For headpointing, no calibration is necessary to reliably use this device.

The setup procedure involves using the PC to configure the Guide to specify the actions of the system controller which are initiated by each user selection. The Guide may be entirely original, or previously stored on the PC. Once specified, it is downloaded to the system controller in order to be used. The second step in the setup phase is the definition of spoken messages which will be presented to the user. The PC may download previously stored messages to the system controller for reuse, or may initiate the recording of new messages. The final step in the setup procedure is the specification of the dwell time and eyegaze or headpointing mode. The dwell time is the length of time the user's gaze must fixate on a desired selection/symbol to initiate any action.

The user must calibrate the eyegaze prototype which is a process by which the system controller develops a correlation between the actual direction of the user's gaze and the perceived direction of the user's gaze as 'seen' by the eyegaze sensor. At calibration, a relation is made between an infrared reflection from the retina/cornea of the eye and a reflector target placed beneath the user's eye. The target creates a point of reference with respect to the position of the pupil so that eye movements may be easily observed by the eyegaze sensor. Calibration is necessary due to the natural variations in the physiology of the eye within the human population and because the reference target cannot be reliably placed in the exact same position during each use. When calibrating, the user gazes at a spot on the display panel for several seconds after having been properly positioned by the clinician/researcher.

To the user, the communication system looks like a panel of pictures with an LED associated with each. When the user gazes at a particular picture, the associated LED lights up. If the user continues to look at that same picture for a period of time (.5 - 8 seconds), then a selection is recognized by the system controller. For example, if the user gazes at the photo of the television, then the system controller lights the display panel LED, waits for the appropriate dwell time, initiates an ECU command to turn on the television, and audibly replays the message which says "I want the television on." The user may continue to make selections one after another or may make a selection, look away from the display panel, then look back again some time later to make another selection.

The system controller stores any action taken by the user in its memory and dates it. This data can then be downloaded to the PC's memory, stored, and output in a format which makes data analysis possible.

Evaluation

The described eyegaze/headpointing prototype was field tested with four students/subjects, ages 6-16, with varying degrees of mental retardation and severe physical handicaps. Although the enhanced and modified prototype was a significant improvement over the original device, there was a continual need to modify and troubleshoot the prototype based on research and clinical input. Through intense training and practice, the subjects all learned to use the technology and their quality of life was greatly improved when they were able to communicate and make choices in their environments for the first time in their lives.

Discussion

The modified Eyetyper used in this research has been tremendously enhanced, yet is still somewhat primitive. This research supports the use of properly designed eyegaze/headpointing technology with people who have mental retardation and points the direction for future research.

References

1. Bricker, D., & Filler, J. (1985). The severely mentally retarded individual: Philosophical and implementation dilemmas. In D. Bricker & J. Filler (Eds.), Severe mental retardation: From theory to practice (pp. 2-11). Lancaster, PA: Lancaster Press, Inc.
2. Brown C.C., (1989). Research focusing on freedom of choice, communication, and independence using eyegaze and speech recognition assistive technology. In A. VanBiervliet & P. Parette (Eds.), Proceedings of the First South Center Technology Access Conference, (pp. 27-34). Little Rock, AR: University of Arkansas at Little Rock.
3. Demasco, P.W., & Foulds, R.A. (1982). The design of an ocular controlled communication system for clinical implementation. In J.P. O'Leary & J.R. O'Reagan (Eds.), Proceedings of the Fifth Annual Conference on Rehabilitation Engineering, (p. 26).
4. Friedman, M.B., Kilinay, G., Dzmura, M., & Anderson, D. (1981). The eyetracker communication system. Proceedings of the Johns Hopkins First National Search for Applications of Personal Computing to Aid the Handicapped (pp. 183-185). New York: IEEE.
5. King, M. (1984). Eyescan. Communication Outlook, 5(9).
6. Rosen, M., Drinker, P., & Dalrymple, G. (1976). A display board for non-vocal communication encoded as eye movements. Proceedings of the Conference on Systems and Devices for the Disabled, (pp. 70-71).
7. Schneider, M.R. (1982). Design of a new communication aid: SPA-SYN-COM. In J.P. O'Leary & J.R. O'Reagan (Eds.), Proceedings of the Fifth Annual Conference on Rehabilitation Engineering, (p. 25).
8. Smith, R.O., Christiaansen, R., Borden, B., Lindberg, D., Gunderson, J., & Vanderheiden, G. (1989). Effectiveness of a writing system using a computerized long-range optical pointer and 10-branch abbreviation expansion. Journal of Rehabilitation Research and Development, 26(1), 51-62.
9. Sutter, E.E. (1983). An oculo-encephalographic communication system. In B.R. Bowman (Ed.), Proceedings of the Sixth Annual Conference on Rehabilitation Engineering (pp. 171-173). San Diego: RESNA.
10. Tello, E. (1988, September). Between man and machine. BYTE, (pp. 288-293).

Carrie Brown, Ph.D.
Bioengineering Program
Association for Retarded Citizens of the United States
2501 Avenue J
Arlington, TX 76006

Funded through E.D. Grant #G008730319-87

P2.6

Your Expressive Society (YES) An Augmentative Communication Users Support Group

Dannel C. Friel
Gillette Children's Hospital

Abstract

Augmentative/alternative communication users and therapists were expressing a desire for more experience and support in the use of their systems. From this desire an augmentative/alternative communication users support group was formed. The group was founded in October 1990, and consisted of eight augmentative/alternative communication users. Group and individual goals and strategies to accomplish them were identified and executed. We have successfully Christmas carolled at a local mall and are planning many other public activities which will enable us to fully participate in society. The presentation will include information on how the group was formed, group activities, examples of individual goals and the joys and sorrows inherent in such a group. A video tape of activities, including Christmas caroling will also be presented.

Background

We have provided augmentative/alternative communication services for individuals of all ages for approximately seven years. In recent years, clients and therapists, utilizing our services, came to us expressing a desire to have more public interaction and communication experience in real life situations. They felt users were not effectively communicating outside the therapy setting. Clients incorporate a variety of augmentative systems while communicating including Real Voice, Touch Talker, Light Talker, coded E-tran system with Bliss Symbols, and manual boards.

Objective

The group primary goals are to practice communicating and to create a support network. The secondary goals are to familiarize communicators and therapists with the capabilities and limitations of the systems and to present users to the public as effective communicators.

Method/Approach

We began by focusing on preparation for structured, public, group activities. We chose our first public activity, singing Christmas carols at a local mall, not only to give us security in numbers, but to allow the public to encounter us comfortably. Preparation consisted of practicing songs chosen by the group at biweekly meetings. This provided a relaxed atmosphere, allowing individuals to become familiar with one another; discovering strengths and weaknesses. Because our first public activity was so successful, the group agreed to continue to meet. The members further defined their needs, which encompassed individual as well as group needs, and new goals were set accordingly. For individuals communication exchanges and strategies for execution are identified, for completion outside the group. Results of the communication exchanges are reviewed at the next meeting. Group activities and strategies which are in areas of interest to a majority of the group, are also identified. The communication exchanges, group activities and meetings are designed to provide opportunities for communicating with a variety of people, in various environments, as well as the sharing of ideas and experiences with others that rely on augmentative communication systems for communicating.

Results

1. The group first met in October, 1990, and included 8 members. More and more people became interested in the group, including users, therapists, other invested personal, and the media.

2. Members learned new features and limitations of their devices. More technical difficulties were encountered then expected.

3. Friendships developed. Members became supportive to one another outside the group, not only for communication, but for other personal needs.

4. Communication became more spontaneous and members are showing more interest in what and how items are programmed into their devices.

5. Public acceptance was surprisingly positive.

Discussion

ALL THE PARTICIPANTS HAVE HAD FUN! We currently have the original eight participants, and are considering expanding membership, including a long distance (via telephone) member.

Despite heavy investment of time necessary to overcome technical difficulties and learn new features, this became an educational activity for participants, as they were able to learn problem solving strategies.

The friendships that have developed indicate how successful and meaningful this support group has become.

We discovered people just wanted to participate in activities that most take for granted, as is apparent in the following sample of planned activities: make telephone calls, initiate conversations, write letters, go on a picnic, put on a play, go shopping, read to elementary students, participate in a backyard newscast, sing again, expand membership. These activities and the communication spontaneity indicate that individuals are learning to exercise more control over their lives.

Group performances provided opportunities for people of the community to observe persons with disabilities, without being self conscience about staring.

Your Expressive Society Is Sponsored By Express Yourself Incorporated and Gillette Children's Hospital

Dannel Friel
Gillette Children's Hospital
200 E. University Ave.
St. Paul, Minnesota 55101

Peg Johnson
Express Yourself, Incorporated
P.O. Box 16374
St. Paul, Minnesota 55416

P2.7

THE EFFECT OF ELECTRICAL STIMULATION ON HEALING RATE IN DIABETIC PATIENTS

L.L. Baker, F. Villar, S. DeMuth, J. Burnfield, R.B. Chambers
University of Southern California, Department of Physical Therapy &
Rancho Los Amigos Medical Center, Ortho-Diabetes Service
Los Angeles, CA USA

ABSTRACT

Electrical stimulation has been proposed as a means of enhancing the healing process in patients with hard-to-heal ulcers. Three types of electrical stimulation, and a control protocol have been studied in a sample of 40+ diabetic subjects. The three stimulation protocols used two different waveforms and frequencies, and three different phase durations. The control protocol provided no stimulation. Preliminary data indicate that the stimulation does enhance the rate of wound healing, especially in subjects with small ulcers. Little difference was seen between the two waveforms used, but a minimum level of current may be necessary to demonstrate the healing enhancement. More subjects treated with each protocol are required before more definitive recommendations regarding stimulation parameters can be made.

INTRODUCTION

Several million persons have reduced resistance to ulceration of the skin and soft tissues. This is most often due to impairment of cutaneous circulation and/or surface areas subject to high levels of external pressure for prolonged periods of time. For over twenty years reports of the therapeutic effects of electrical stimulation in facilitating wound healing have sporadically appeared in the literature. To date only two reports of controlled studies designed to determine the degree of efficacy electrical stimulation may impart to the wound healing process have been located in the literature (1,2). These studies assessed the effectiveness of two very different forms of electrical stimulation on small, heterogenous patient samples. Although the results from these studies, and others assessing healing in animals models (3,4), are promising, many questions related to mechanism, etiology, and stimulus parameters remain unanswered.

This paper is the first report from an ongoing study designed to prospectively assess the effects of three forms of electrical stimulation on the healing of diabetic ulcers. Further work in the spinal injured population will provide additional information relating ulcer etiology, healing times and stimulation effects (5). A control group, receiving no stimulation, has been included in this diabetic patient sample.

METHODS

Three forms of electrical stimulation, all either described in the literature or traditionally used in the clinic, are being evaluated for their effects on healing rate. A fourth group of subjects have served as non-stimulated control patients. All subjects have been physician approved for participation in the study, and all have agreed to participate in the study, without knowledge of which treatment group they were assigned. All subjects received physician prescribed treatments, with the stimulation added to their regimen. Ventilatory function and nourishment status were monitored, as was the quality of subject's diabetic control. Most patients had experienced some form of wound infection, assessed through wound culture. All subjects with infections were placed on aggressive antibiotic therapy prior to entering the stimulation study.

Electrical stimulation treatment protocols included three 30 minute treatment sessions per day, 5-7 days a week. All patients were given stimulators (Ultrastim by Neuromedics, Houston TX) which cycled to a pre-set amplitude for the desired treatment time. Patients in the control group carried out the same protocol as other patients, but the lead wires to the patient had been disabled and could not carry current. The four treatment protocols consisted of:

A) Asymmetric balanced biphasic pulse of 0.1 ms duration set at a frequency of 50 pps. Amplitude was set below motor contraction levels.
B) Symmetric balanced biphasic pulse of 0.3 ms duration set at a frequency of 50 pps. Amplitude was set below motor contraction levels.
AM) Symmetric balanced biphasic pulse of 0.01 ms duration set at a frequency of 1 pps. The amplitude for this average microcurrent group was arbitrarily set to 4 mA.
C) The non-stimulated control group used the AM protocol and the disabled lead wires.

Electrical stimulation was applied through electrode placements which included the area of ulceration but minimized the likelihood of creating a stimulated muscle contraction. Electrodes were placed around the area of ulceration, but not in contact with the wound.

Every one to two weeks the research therapist assessed the size of the ulcer(s) on each patient. This was done by taking a photographic close-up with a ruler in the picture. Photographs were subsequently digitized for both area of the wound and the perimeter around the wound. Deeper ulcers were assessed by measurement of the volume of sterile saline required to fill the ulcerous cavity. This technique, however, was often not possible in the diabetic patients who demonstrated foot ulcers.

Data analysis was done by converting the data to a rate of healing value. Rate of healing was defined as the difference between the present wound size and the original wound, divided by the original wound size and divided again by the number of days between the two measures. When multiplied by 7, this was interpreted as the percentage of wound closure per week.

RESULTS

A total of 51 diabetic patients have been, or are being, treated in the research project. Data from 40 wounds have been subjected to statistical analysis at this time. Because of the small number of wounds in each treatment group, analysis has been restricted to descriptive statistics only at this time. Data are presented in Table 1. It can be seen that the three stimulation groups have a slightly better rate of wound healing then does the non-stimulated control group, although the number of wounds in each treatment are very small.

Table 1. Healing Rates for All Diabetic Wounds

Treatment	Rate of Healing (percent closure/week)	Number of Wounds
A	16 ± 5.6	10
B	14 ± 2.7	13
AM	14 ± 3.0	13
C	12 ± 1.1	4

Because the number of control wounds is so very small, and by chance most of the control wounds were small in size to begin with, the data were further stratified for evaluation of only those wounds which had an initial area of less then 5 cm^2. These data are presented in Table 2. The stimulation group receiving the symmetrical biphasic waveform demonstrated a considerably greater rate of wound closure then the groups receiving minimal stimulation levels (AM) or no stimulation (C). These data are, however, very preliminary at this time.

Table 2. Healing Rates for Wounds less then 5 cm^2

Treatment	Rate of Healing (percent closure/week)	Number of Wounds
B	20 ± 4.5	5
AM	12 ± 2.7	7
C	13 ± 1.5	3

DISCUSSION

Although our data is preliminary, it does appear that electrical stimulation enhances the healing process in diabetic patients, even when they are receiving relatively aggressive 'standard care'. More subjects must be added to the data base before specific recommendations regarding stimulus protocols can be made. The apparent therapeutic effect of the AM treatment group, which received a minimal amount of actual current, was unexpected and will require further evaluation. It may be that the rate of healing enhancement is dependent upon the size of the initial wound, as suggested by Table 2. Further stratification by wound size and other variables, such as presence or degree of neuropathy, will require expansion of the present data base. Our goal is to treat a minimum of 20 patients in each group by the completion of the study later this year.

Addition of electrical stimulation to standard wound management appears to enhance the healing process, as shown by this preliminary data and reported by other investigators (1-4). This study has evaluated the effects of the treatment intervention in a sample with similar etiology, i.e., diabetes. This is the only study to date which has attempted to evaluate the effects of stimulation on a sample with similar pathophysiology. The effects of electrical stimulation may or may not be the same in other patient populations. A companion study, evaluating spinal cord injured patients with decubital ulcers, may assist in determining the specificity of the therapeutic stimulation effect (5).

Preliminary data from transcutaneous oxygen assessment (6) indicate that increased circulation and oxygen delivery to the stimulated tissues may be at least one physiologic effect enhanced by the addition of electrical stimulation. Other physiologic effects of the stimulation may become evident as the data base is expended and more effective stratification can be done. A bacteriostatic effect of stimulation has been proposed and since many of our patients were infected it may be possible to assess the rate of clearance of the organisms. All of these patients, however, were undergoing very aggressive antibiotic treatment, so a high rate of micro-organism destruction wound be anticipated. A difference in the number and rate of clean wounds in the A and B treatment groups, compared to the AM and C groups, would lend credence to a bacteriostatic effect.

While there is much yet to be done before the type of electrical stimulation best suited to enhancement of wound healing can be determined, the present study has begun to demonstrate similarities and differences between three stimulation protocols. While waveform does not seem to be a major factor in determining healing rates, as demonstrated by the similarities of the A and B treatment protocols, a minimal level of current may be, as shown by the negligible effect of the AM protocol, especially in the subgroup with small wounds. Further assessment of these protocols in an expanded sample will hopefully provide more specific recommendations for the clinician who chooses to add electrical stimulation to their treatment regimen for the management of hard to heal wounds.

ACKNOWLEDGEMENTS

Funding for this research has been provided in part by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant No. H133A80040-90. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of NIDRR.

REFERENCES

1. Carley PJ, Wainapel SF: Electrotherapy for acceleration of wound healing: Low intensity direct current. Arch Phys Med Rehabil 66: 443-446, 1985.

2. Kloth LC, Feedar JA: Acceleration of wound healing with high voltage, monophasic, pulsed current. Phys Ther 68: 503-508, 1988.

3. Rowley B, McKenna J, Chase G: The influence of electrical current on an infecting microorganism in wounds. Ann NY Acad Sci 238: 543-551, 1974.

4. Brown M, Gogia PP: Effects of high voltage stimulation on cutaneous wound healing in rabbits. Phys Ther 67: 662-667, 1987.

5. Libanoff S, Sato K, Baker LL: Electrical stimulation and transcutaneous oxygen changes in spinal cord injured patients with ulcerations. Physical Therapy 66th Annual Conferance, June, 1991.

6. Dodgen PW, Johnson BW, Baker LL, Chambers RB: The effects of electrical stimulation on cutaneous oxygen supply in diabetic older adults. Phys Ther 67: 793, 1987.

Lucinda L. Baker, Ph.D.
Rancho Rehab. Engineering Program
7503 Bonita Street - Bonita Hall
Downey, CA 90242

P2.8

Multichannel Electrical Stimulation System for Gait Assist and Cyclical Stimulation

Paul Meadows, Joyce Campbell, Robert Waters, Chris Jordan & Cindy Wederich
Rancho Rehabilitation Engineering Program
Downey, CA

ABSTRACT

A portable eight channel Functional Neuromuscular Stimulation (FNS) system has been designed to support research in the application of electrical stimulation to gait assist in stroke patients. This portable system may be worn by a patient during gait or used as a table-top multichannel cyclical stimulation system. Non-volatile memory is used to store all cyclical and gait stimulation parameters as well as stimulation calibration data. The device is programmed for a patient via a CRT terminal. System description and case history data are presented.

INTRODUCTION

Electrical stimulation has been utilized by many researchers and clinicians to facilitate gait in patients with neurological deficits. This has also been a major research interest at our center for a number of years now in the areas of both therapeutic and functional applications. The device described here is the result of that interest and the development of numerous multichannel stimulation systems, including standard surface electrode and implanted electrode systems and implanted stimulator and electrode systems.

A number of portable multichannel stimulation systems have been developed to facilitate gait in hemi- and paraplegic persons at major research centers around the world. Gait training of stroke patients with first custom and then a few years later with commercially available dual channel stimulators has been a regular part of treatment at our medical center for years. The dual channel stimulator originally developed at our center could be triggered by footswitches and secondary stimulators could be linked to expand stimulation channel capability.

In Ljubljana, a six channel microprocessor based stimulator was developed which used heelswitches to detect stance and swing and which could regulate the delivery of stimulation based upon timing information derived from the heel switches (10). More recently Ljubljana has developed smaller and lighter, microprocessor based dual channel stimulators which rely upon sensory nerve stimulation to elicit the withdrawal reflex and thus initiate swing (1).

At Case Western Reserve University and the VA Hospital in Cleveland, 32 channel systems have been developed to stimulate the lower limb and trunk musculature of paraplegics for standing, ascending and descending stairs and level ground walking (6). Case is currently developing an implantable 8 channel system (8) which will replace the 32 channel system above and an external 16 channel system (2) used for upper extremity stimulation for restoration of hand function in C5-C6 quadriplegia.

Other implanted systems have been developed to replace external systems. Our center, using the chip set from a cochlear prosthesis developed by Stanford (5) has developed an 8 channel implantable stimulation system which could be used with nerve cuff electrodes (7). More recently implantable devices with sixteen or more channels have been presented by researchers in London (4) and by MiniMed of California (9). Of course, most all of the aforementioned devices are not commercially available, and in particular, implantable systems will not be available to clinical researchers in sufficient quantity for several years to come. The stimulator described in this paper was designed to meet a number of design requirements. We needed a device which would support at least eight channels, would work for both therapeutic training and functional use, would work with different types of surface and implanted electrodes, would be portable and light enough to be practical for gait, and would be microprocessor based to allow a variety of control algorithms and interfaces to be implemented. Since no commercial devices meet these criteria, nor are any research devices available from other centers, we have continued to develop our own stimulation equipment.

DESIGN

System Specifications

A summary of the stimulation specifications for the stimulator may be found in Table 1. The stimulator has eight active stimulation channels, but has sixteen outputs, with eight indifferent electrodes, any one or more of which may be assigned to an active electrode channel.

Table 1. Stimulation Specifications:

Number of Channels:	8
Electrode Configuration:	Mono/Bipolar
Stimulus Waveform:	Asymmetrical or Symmetrical Biphasic
Maximum Current:	150 mA, 1K load
Current Resolution:	1 mA
Pulse Duration Range:	10 - 350 us
Pulse Duration Resolution:	1
Inter Pulse Interval (IPI):	10 - 1000 ms
IPI Resolution:	10 ms
Pulse Interphase Delay:	50 us
Stimulus Ramp Up/Down:	1-200 pulses

Description of Hardware

The portable stimulation system resides in a plastic enclosure measuring 7.5"x4.5"x2.5" and has two eight pin RJ45 connectors for eight channels of bipolar stimulation electrode connections, two six pin RJ12 connectors for five channels of digital and analog input to the stimulator system for triggering information, a four pin RJ11 connector for RS-232 serial communication to a host terminal or computer and a charging jack. A two line LCD display module is used for all messages and menu options in conjunction with a three pushbutton array on the side of the chassis above the connectors.

Internally there are three circuit assemblies. The first is a backplane with power management circuitry including: a dual level float charger circuit for the internal 12VDC 0.8AHr sealed lead-acid battery, a 12VDC to 5VDC switching regulator and a 5VDC to +/-15VDC dual switching regulator.

The second assembly is the CPU board which utilizes the Motorola MC68HC11A1FN eight bit CMOS microprocessor. Table 2 describes the specifications for this circuit board.This board connects to the backplane with a proprietary 50 pin bus.

Table 2.: CPU Board Specifications

Microprocessor:	MC68HC11A1FN
Bus Speed:	2 MHz
CPU RAM:	256 Bytes
CPU EEROM:	512 Bytes
CPU A/D System:	8 Channel, 8 Bit
EPROM Space:	32 KBytes
RAM Space:	8 Pages, 32 KBytes each, Battery Backed
Serial Port:	RS-232, 9600 Baud
Digital I/O:	16 Input, 8 Output
Display Interface:	Seiko M1632 2 line x 16 character LCD Module
Microprocessor Security:	MAX691 Supervisor and backup battery controller
Backplane:	50 pin proprietary

The third assembly in the system is a biphasic pulse generator. This board connects to the system with the 50 pin bus and has on board control and timing registers to generate monopolar or bipolar, asymmetrical or symmetrical biphasic stimulation pulses of any magnitude up to 150 mA and phase durations up to 350 microseconds on any of eight channels. Once loaded with stimulation information, pulse generation is carried out automatically by this assembly. No high voltage power supply is required by this board.

Electrodes currently in use are surgically implanted epimysial electrodes (3), although any surface or implantable electrodes could be used. These electrodes are titanium disks, approximately 1 cm in diameter which are attached to silicon impregnated dacron mesh sheets which are sutured to the muscle of interest at the point of nerve entry to the most excitable region of the muscle when the nerve twig is inaccessible. A silicon insulated, coiled, multistranded stainless steel wire is attached to the electrode and is brought out percutaneously to an external multi-pin connector.

Operational Description

The stimulator operates in three modes: programming, cyclical stimulation and gait stimulation. Any serial terminal or computer system can be attached to the stimulator's RS-232 9600 Baud port and any of its programming functions can be selected. These functions include: storage of patient identification, calibration of stimulus output characteristics, programming of cyclical stimulation and programming of gait stimulation parameters. All programmed parameters are stored in CPU EEROM, a non-volatile form of read/writable memory.

Cyclical stimulation parameters include: treatment duration in minutes; rest time between stimulation bursts in seconds; stimulation amplitude in mA for all eight channels; stimulation ramp up/down/hold times; stimulation waveform (symmetric or asymmetric biphasic); electrode configuration for each channel (mono/bipolar); if bipolar electrode configuration, then which indifferent electrode(s) are associated with each of the eight active electrodes; the stimulation Inter Pulse Interval (IPI) for each channel in ms; the pulse threshold and maximal phase durations to be used in ramp up/down; and the delay of triggering for each channel from the group trigger.

Gait stimulation programming includes all of the above except treatment and rest time parameters, with the addition of the following parameters: whether a pressure sensor or a heel switch is used for gait triggering; if a pressure sensor is used, then the pressure on/off limits are requested; whether each channel is associated with heel on or off for trigger source; what the delay from trigger event is for each channel in milliseconds; and finally whether or not the stimulator should continue to re-trigger itself in stance if the swing phase is not initiated.

APPLICATION

In a Research and Development Project funded by the National Institute on Disability and Rehabilitation Research, we have used this portable stimulation system to study the short term application of implanted epimysial electrodes with percutaneous leadwires and multichannel electrical stimulation for improvement of gait in stroke and head trauma patients. Epimysial electrodes (described previously) were implanted on muscles which are difficult, if not impossible, to selectively stimulate at functional intensities with surface electrodes. Electrodes were implanted at the same time as surgical intervention to improve foot posture. The insulated coiled leadwire is brought percutaneously to a Cannon ITT connector block. The coiled wire allows the leadwire to flex and to extend with limb movement, to prevent irritation, infection and leadwire breakage.

CASE REPORT

One of our patients, KB, is a 46 year old female, 1.5 years post stroke patient who was implanted in July of 1990 with nine epimysial electrodes: one on the gluteous medius and four on the gluteus maximus and two on the long head of the biceps femoris muscles for stance support, and two on the short head of the biceps femoris to assist during the swing phase of gait. KB's gait characteristics are summarized in Table 3 below. The initial measurements were made prior to electrode implantation and final measurements were taken in October, 1990.

Table 3. Gait Measurements for KB

	Velocity	Cadence	Stride Length	Knee Angle @HS	Peak Hip Angle
	m/min	step/min	m	deg	deg
Initial	23	36	0.65	20	22
Final	37	40	0.91	9.8	27

From the data above it can be seen that there was an increase in gait velocity, number of steps per minute, and length of each stride, all of which indicate that KB could walk faster and farther with the stimulation system than before. The knee angle at heel strike measurement indicates that KB was able to straighten her leg much better at the termination of swing phase for more stable single limb support.

DISCUSSION

The eight channel stimulation system is improving walking in our stroke patients. The system has grown from its original eight channel monopolar, 60 mA system version, to a version which would support two eight channel RF powered implantable stimulation devices. The system is currently being evaluated at the Division of Neuroscience, University of Alberta, at the University of Utah Medical Center, and is soon to be evaluated at the Division of Restorative Neurology and Human Neurobiology at Baylor Medical School and at the Mobility Research and Assessment Laboratory at the Southwestern Medical Center of the University of Texas. The power, number of channels, package and operational features have proven to be very beneficial to our research programs and we hope to the programs mentioned above as well.

ACKNOWLEDGEMENT

This research has been supported by a grant from the National Institute on Disability and Rehabilitation Research (NIDRR), U.S. Department of Education, #H133A80042. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of NIDRR.

REFERENCES

1. Bogataj, U., Kelih, G., Malezic, M., Filipic, D. and Kljajic, M.: Dual-channel electrical stimulator for correction of gait, Adv Ext Cont Human Ext, pp. 327-333, Dubrovnic, 1990.
2. Buckett, J.R., Braswell, S.D., Thrope, G.B. and Peckham, P.H.: A microprocessor based portable functional electrical stimulation system. Proc 6th Annu Conf Rehabil Eng, San Diego, CA, pp. 72-74, 1983.
3. Campbell, J., Nakai, R. and Waters, R.L.: Epimysial electrical stimulation: short-term therapeutic applications, Tenth Annu Conf Rehabil Eng, San Jose, 1987.
4. Donaldson N. de N.: A new multiplexed stimulator for FNS, Adv Ext Cont Human Ext, pp. 345-358, Dubrovnic, 1990.
5. Galbraith, D.C.: An implantable multichannel neural stimulator, Doctoral Thesis, Stanford University, 1984.
6. Kobetic, R., Vance, F. and Marsolais, E.B.: 32-channel portable programmable stimulator for walking of paraplegics. Proc 2nd Int Conf Rehabil Eng, Ottawa, pp. 533-534, 1984.
7. Meadows, P.M., McNeal, D.R., Su, N.Y., and Tu, W.W.: Development of an implantable and percutaneous electrical stimulation system for gait applications in stroke and spinal cord patients. Adv in Ext Cont Human Ext, pp. 51-64., Dubrovnic, 1987.
8. Smith, B., Peckham, P.H., Keith, M.W. and Roscoe, D.D.: An externally powered, multichannel, implantable stimulator for versatile control of paralyzed muscle, IEEE Trans Biomed eng, BME-34:499-508, 1987.
9. Strojnik, P., Whitmoyer, D. and Shulman, J.: An implantable stimulator for all seasons, Adv Ext Cont Human Ext, pp. 335-343, Dubrovnic, 1990.
10. Trnkoczy, A., Stanic, U., Malezic, M., Acimovic, R. and Gros, N.: The development of multichannel FES stimulators for gait correction in paretic patient. Proc 1st Medit Conf Med Biol Eng, 1977.

MAILING ADDRESS

Paul Meadows, M.S.
Senior Engineer
Rancho Rehabilitation Engineering Program
7503 Bonita Street
Downey, California 90242
Voice: (213) 940-7994
FAX: (213) 803-6117

P2.9

TRAINING TOOLS FOR A NEUROPROSTHETIC HAND SYSTEM

Brian T. Smith, M. J. Mulcahey, Ronald J. Triolo, and Randal R. Betz
Functional Neuromuscular Stimulation Laboratory
Shriners Hospitals for Crippled Children
Philadelphia, PA

ABSTRACT

Clinical tools are being developed to train children with cervical level spinal cord injuries (SCI) and spastic quadriparesis, cerebral palsy (CP) in the control and operation of a neuroprosthetic hand system. A shoulder transducer used to control grasp stimulation has been interfaced to a remote control car and personal computer to simulate all aspects of hand system operation. Both training aids will be adapted so that various control sources and techniques can be implemented and evaluated. Two subjects have used the remote control car and one subject has used the computer simulation. Protocols are being developed to use these training tools on a consistent basis to train all future hand system users.

BACKGROUND

Our research laboratory is implementing a neuroprosthetic hand system [1,2] to restore hand function in children with cervical level spinal cord injuries and spastic quadriparesis, CP. For children with spinal cord injuries, lateral and palmar prehension patterns are developed; for children with CP, functional patterns are developed to enhance voluntary control and to counterbalance spastic motor patterns.

The neuroprosthetic hand system consists of percutaneous intramuscular electrodes implanted in muscles of the hand and forearm, a multi-channel, microprocessor controller that delivers stimulation current at programmed frequencies and pulsewidths, and a shoulder position transducer for grasp control. The shoulder transducer translates the position of the contralateral shoulder (relative to the sternum) to an electrical signal that is interpreted by the stimulation unit as a measure of the amount of grasp flexion desired. In this way, an individual can continuously control a grasp by either depression and elevation or retraction and protraction movements of the shoulder. A switch mounted on the transducer allows the user to choose a functional pattern. When the control switch is depressed, audio cues provide feedback concerning the system mode (grasp selection, on/off, etc.).

Studies have been performed to evaluate shoulder movement as a control source for the neuroprosthetic hand system. The shoulder transducer has been interfaced with various devices including an X-Y plotter [3], personal computer [4] and graphics controller [5], to provide visual feedback on shoulder movements. Results of these studies have shown that contralateral shoulder movement is an effective method for adults with C5 and C6 spinal cord injuries to control a neuroprosthetic hand system.

STATEMENT OF PROBLEM

The neuroprosthetic hand system was designed for and has been used primarily by adults with spinal cord injuries. Over the past two years this technology has been adapted to restore or augment hand function in the pediatric SCI and CP populations. The diversity of motor, cognitive, and perceptual skills encountered in these populations requires individualized system training and investigation of alternative control techniques. Presently, there are no clinical tools to train these children to operate the neuroprosthetic hand system, or to evaluate new or enhanced methods of control.

RATIONALE

In order to use the neuroprosthetic hand system functionally, children with spinal cord injuries require retraining in control of residual proximal motor function and training in compensatory skills for balance and mobility; children with CP require training to compensate for motor, perceptual, and cognitive limitations. These characteristics, coupled with the unique approach to rehabilitation required within the pediatric population, demonstrate the need to design training and evaluation tools for the hand system.

The importance of these training aids lies in the ability to use them before functional grasp patterns are created. Currently, subjects are introduced to the operation of the shoulder transducer only after grasps have been established. This process typically takes at least six weeks of electrode implantation, immobilization, and stimulated exercise. This is an optimal time to train a subject in the operation of the stimulation system, and to determine the user-specific control parameters.

Interactive tools which simulate aspects of system operation and can be used to determine control parameters, can make a subject a competent user before functional grasps are finalized. With such tools, present shoulder control techniques can be enhanced and evaluated, and alternative means of grasp control can be investigated for subjects whose cognitive and/or physical limitations render the shoulder transducer inappropriate.

DESIGN

The shoulder transducer has been interfaced with both a remote control toy car and an IBM 386 computer. Interfacing the shoulder transducer to a remote control car allows the user to become familiar with the shoulder motion and button activation employed during hand system operation. The computer offers the programming flexibility, graphics capabilities, speed, and tone generation neccessary to simulate completely the operation of the neuroprosthetic hand system.

Remote-control car

The remote-control car can be operated with the shoulder transducer in two ways. First, by moving the shoulder from a depressed or retracted position, through neutral, to an elevated or protracted position, the car will move in reverse, stop, and then forward, respectively. In the second mode, the control switch is continuously activated to force the car to move forward. As the shoulder is ranged from a position of depression or retraction, through neutral, to an elevated or protracted position, the car will now turn left, go straight, and turn right, respectively.

The interface allows the range of shoulder motion that controls each car movement to be adjusted to the needs of the individual. As a user becomes more profficient controlling the car the ranges can be reduced, thus requiring finer shoulder control to "find" a desired car direction. Conversely, for a user who has difficulty with shoulder control, the ranges can be expanded. This feature is used to quantify changes in proximal shoulder control using the shoulder transducer.

Computer simulation

A menu driven program written in Borland Turbo C simulates the entire hand system. The simulation allows the input of system parameters such as shoulder transducer gain, threshold velocity, and control axis. When the control switch is depressed, the computer generates the appropriate audio tones and a status banner on the screen highlights the operating modes. With the shoulder fully retracted or depressed, the user releases the control switch and a two dimensional graphical representation of an extended hand appears for the desired grasp. Depending on the control axis, as the operator protracts or elevates the shoulder, the animated hand closes. A command range gauge indicates the fraction of full grasp flexion at any given time. With the simulation, the operator can practice opening and closing the hand to determine if the transducer parameters should be modified.

DEVELOPMENT

The long range goal of this project is to use these tools clinically to determine the optimal control modalities for each subject; once established, the skills neccessary to operate the neuroprosthetic hand system can be strengthened.

Various control sources and techniques will be adapted for use with the remote control car and the computer. New methods of control can be tested and refined with these training tools, allowing us to better evaluate the feasibility of their functional use. The simulation program will also be expanded to include tracking tasks and games which emphasize the isolation of shoulder movements.

Protocols will be established to use these tools throughout a subject's participation in the program as well as during the physical screening evaluation to determine if an individual can use the shoulder transducer to control grasps.

EVALUATION

The remote control car was used with both a nine year old child with a C7 level SCI (SP), and a ten year old child with hemiparesis, CP (DG). The hand system simulation was used with a 20 year old with a C5 level SCI (RB).

The remote control car was incorporated into SP's system training. When SP began to train with the car he used the protraction/retraction shoulder movements to control car direction. During this first attempt, SP was asked to move the car forward and backward between two cones placed ten feet apart. He had difficulty stabilizing his trunk to elicit proximal shoulder movements, especially when moving the car backwards with retraction of the shoulder. For the next training session, the control axis was changed so that SP could use the elevation/depression shoulder movements to control the car. After a short period of practice, SP could easily manipulate the shoulder transducer to make the car move back and forth between the cones. During the third session, the shoulder ranges

BEST COPY AVAILABLE

that permit the car movements were reduced. SP could still easily perform the car control task indicating that proximal muscle control may have improved in fine coordination. Using the remote control car system, the proper shoulder control axis was determined, and the neccessary shoulder motions were mastered before SP was able to use the complete stimulation system. Because of this initial training, subsequent instruction could be focused on quality of prehension for functional use instead of shoulder control.

Subject DG participated in a pilot study that provided baseline information for an expanded effort to implement the hand system with the cerebral palsied population. As part of this study DG donned the transducer on the right shoulder (contralateral to her involved upper extremity) and was asked to perform the same car control task as SP. The car was placed in front of DG so that when the car moved back and forth it crossed her field of vision. DG encountered a problem retracting her shoulder (to move the car backwards) when the car was positioned to her left. Because of her left neglect she had to turn her head away from her instrumented shoulder to maintain visual contact with the car while simultaneously retracting her shoulder. This test was not repeated using elevation/depression shoulder movements, but similiar problems were anticipated. If DG participated in the hand system program, emphasis would be placed on practicing shoulder movements while concentrating on an object in her field of vision left of midline.

RB was asked to use the simulation program to provide feedback concerning its use. As an experienced hand system user, he had several suggestions on how the program could be enhanced including eliminating keyboard inputs and incorporating help functions that describe program operation. With these changes RB felt that the program could be used without assistance, a feature that he felt was vital to the success of this learning tool.

DISCUSSION

Using the remote control car, shoulder control problems specific to each subject were identified. It is anticipated that similar problems of balance and coordination will be encountered with future subjects. Perceptual difficulties, like those seen with DG, are also likely to be found in children with spastic quadrapresis, CP.

The future success of these tools will be gauged by their ability not only to train future subjects to use the neuroprosthetic hand system and isolate potential control problems, but also to implement and evaluate alternative techniques of stimulation control.

ACKNOWLEDGEMENTS

Funding for this research was provided by Shriners Hospital for Crippled Children Grant #15954 in collaboration with Case Western Reserve University. Wendy D'Hollosy, graduate student at the University of Twente, The Netherlands, wrote the software for this project. Ron Hart, Tony Ignagni, and Jim Buckett, Case Western Reserve University, contributed insightful suggestions and provided transducer documentation.

REFERENCES

1. Kilgore KL, Peckham PH, Thrope GB, Keith MW and Gallaher-Stone KA, "Synthesis of Hand Grasp Using Functional Neuromuscular Stimulation," IEEE Transactions on Biomedical Engineering, 36: 761-770, 1989.

2. Buckett JR, Peckham PH, Thrope GB, Braswell SD, and Keith MW, "A Flexible, Portable System for Neuromuscular Stimulation in the Upper Extremity," IEEE Transactions on Biomedical Engineering, 35: 897-904, 1988.

3. Mortimer JT, Bayer DM, Lord RH, and Swanker JW, "Shoulder Position Transduction for Proportional Two Axis Control of Orthotic/Prosthetic Systems," in The Control of Upper-Extremity Prostheses and Orthoses; P. Herberts et al., eds. Springfield, Il:, Charles C. Thomas, 1974.

4. Limpert B, "A Velocity Control Strategy for a Functional Neuromuscular Stimulation Hand Orthosis," M.S. thesis, University of Toronto, Toronto, Ontario, Canada, June, 1989.

5. Johnson MW, Peckham PH, "Evaluation of Shoulder Movement as a Command Control Source," IEEE Transactions on Biomedical Engineering, 37:(9) 876-885, 1990.

Brian T. Smith
FNS Laboratory
Shriners Hospitals for Crippled Children
8400 Roosevelt Blvd.
Philadelphia, PA 19152

Evaluation of the CASE Multichannel FNS System for Restoration of Hand Function in C5-C6 Quadriplegics

Paul Meadows, Karen Goss, Joyce Campbell, Harris Gellman and Robert Waters
Rancho Rehabilitation Engineering Program
Downey, CA

ABSTRACT

Our center is one of four centers chosen to evaluate a multichannel Functional Neuromuscular Stimulation (FNS) system for restoration of grasp in C5-C6 quadriplegics. Over 150 potential subjects have been screened for inclusion in the study and one subject is currently using the system. The functional benefits as well as firmware modifications and outcome are described.

INTRODUCTION

Spinal cord injury affects over 177,000 persons in the United States today, with a prevalence rate of 721 cases per million (2). A significant percentage of these persons have lesions at the C5-C6 level, rendering them extremely dependent upon other persons and services for their daily personal and vocational functions. Any system which can reduce this level of dependence has the potential of improving the emotional and physical well-being of SCI patients, as well as reducing the economic impact of their dysfunction.

Several years ago a team of researchers at Case Western Reserve University in Cleveland, Ohio, began to develop a multichannel FNS system to aid quadriplegic patients (3,4). Funding was provided by the National Institute on Disability and Rehabilitation Research. The percutaneous version of the Case system is now being evaluated at our center and at three other centers: Shriners Crippled Children's Hospital in Philadelphia, the University of Alberta in Edmonton, and the University of Toronto, Canada.

INSTRUMENTATION

The stimulation system permits the quadriplegic to regain control of palmer and lateral prehension through chronically indwelling percutaneous electrodes. Stimulation is controlled by a shoulder position transducer worn on the contralateral shoulder. The transducer senses proportional movement in two axes and permits smooth modulation of muscle force generation by shoulder protraction and retraction. A locking feature in the transducer (logical control by shoulder elevation) facilitates ease of activities that require prolonged grasp (writing or eating). The 16 channel stimulation system, carried in a camera case attached to the wheelchair, is connected to the percutaneous leads via a small pin connector.

PROGRESS TO DATE

Our first subject, Mary, became quadriplegic in an auto accident at age 45 (December, 1988). Although she can volitionally activate a few motor units in the C6-T1 muscles, volitional muscle test grades for the hand muscles range from Zero to Poor Minus. Sensation is impaired to absent in the forearm and hand.

Mary's 16 forearm and hand electrodes were implanted in three sessions (in surgery at the time of thumb IP fusion and two sessions in subsequent visits to the clinic). A stabilization period of 1-2 weeks was allowed after each implantation session before electrode profiling (the determination of electrode/muscle response to stimulation parameter variance) and functional stimulation were begun. A cyclical stimulation protocol increased force production and fatigue resistance of the implanted muscles. An additional benefit of this exercise protocol has been a reduction in wrist flexor spasticity, resulting in greater electrically stimulated wrist and finger extension.

Within two months after electrode implantation Mary was able to use the FES system for writing and eating. Although the provision of gross prehension was rapid when compared to reports from other centers, Mary's wrist extension is not sufficient at this time to permit discontinuation of the wrist orthosis.

As a grandmother and a college student headed for a degree in computer programming, Mary has many additional goals for the system including the use of telephones, computer accessories and audio/video tapes. Accomplishment of these goals is in progress.

DISCUSSION

While Mary was able to use the FES system for writing and eating within two months after electrode implantation, she has yet to achieve sufficient function in these tasks despite several months of electrically stimulated exercise. The longest period of functional use continues to be about one page of writing and approximately ten minutes of self-feeding compared to practically unlimited durations using her mechanical orthoses. Considering that it takes additional time to set up the FES system for use, that regular exercise is required and that the stimulator must be charged regularly, this represents a significant limitation in the utility of the system.

Despite repeated electrode implantations and training Mary still does not have adequate electrically stimulated thumb extension for activities such as hand opening to pick up a pencil. The pin used in the thumb IP fusion causes pain due to the pin pressure during palmer pinch at this time and will require removal in the near future.

A significant problem area is the programming of information for the stimulator. The software provided to the clinical team at each center is a sophisticated set of programs which has taken a tremendous amount of effort to produce by Case personnel. A number of help screens have been provided and many useful error messages are available to guide clinicians in the use of the system.

However, in a system as complex as this multichannel system where any number of variables can make a significant difference in the grasp pattern, it would be desirable to be able to make adjustments in the grasp pattern controls and to immediately see the results of those changes in prehension. This is not possible with this system because it is necessary to go through a number of steps before changes in prehension are achieved and observed.

Briefly these steps involve first running a program called GRASP in which changes are made in the grasp pattern. After this a program called MAKEPROM is used to select a grasp pattern for lateral and palmer grasp and two patterns for exercise modes. The data produced from this program are transferred to an EPROM programmer and the amplitude for any channels which is not set to 20 mA must be manually changed. An EPROM must then be programmed and finally this EPROM must be exchanged with the EPROM inside the stimulator before the results of the grasp pattern modification may be observed.

While this is obviously tedious, it also can make it very difficult to perceive and evaluate changes in the grasp pattern which are subtle, yet important. This problem will be at least partially addressed in a version of the stimulation system currently being produced which will not require EPROM substitution. A further improvement would be to eliminate the process of selecting grasp pattern output files and the need to generate downloadable files altogether and be able to directly modify the stimulator characteristics online.

One of the biggest obstacles in the system software is the inability of the system to accommodate current amplitudes other than 20 mA, except by manual manipulation of the contents of the EPROM on the programmer. The system works under the assumption that with appropriate electrode placement, sufficient control of the range of muscle activation may be achieved with only pulse duration modulation, this range being from 1 to 255 uSec. For electrodes which are located very close to the target nerve, the gain relationship, or the control input command to the observed force production output, is often too great, resulting in changes of only a few uSec in pulse duration causing great changes in muscle force output. This can be alleviated by simply reducing the stimulation current amplitude for that channel, which is supported by the hardware of the stimulator, but which is not yet supported by the PROFILE and GRASP programs which generate the EPROM for stimulus control.

Comfort is an issue in patients with residual sensation. Clinical experience and experimental projects have shown that a 300 us pulse duration is preferred over shorter pulse durations (1). In view of the large number of potential FNS hand system candidates who retain some sensation, the ability to alter stimulus amplitude is warranted.

One of the problems associated with the quality of Mary's grasp has been the inability to obtain stimulator output in one of the implanted electrodes after it was added to the desired grasp pattern. Despite information provided by the GRASP software program, one of the electrodes selected in the pattern does not appear in the final control chip produced, unbeknownst to the clinician. This problem will no doubt be worked out, but this points to the difficulty in using the software provided.

In general, the system does meet our expectations and the support of the staff at Case is excellent. There are monthly conference telephone calls, and any problems in use of the software, equipment, or any other facet of the program are immediately addressed. Mary has been extremely patient with both our ability to implement the system and with the results of her system. We continue to screen for additional subjects for the program and will continue to evaluate this promising FNS aid for the enhancement of vocational and lifestyle expectations in SCI.

ACKNOWLEDGEMENT

This research has been supported by a grant from the Spinal Cord Research Foundation and the Rancho Los Amigos Foundation. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of either of these foundations.

REFERENCES

1. Baker, L.L., Bowman, B.R. and Mcneal, D.R.: Effects of waveform on comfort during neuromuscular electrical stimulation, Clin Orthop, 233:75-85, 1988.

2. Harvey, C., Rothschild, B.B., Asmann, A.J. and Stripling, T: New estimates of traumatic SCI prevalence: a survey-based approach, Paraplegia, 28:537-544, 1990.

3. Peckham, P.H., Mortimer, J.T and Marsolais, E.B.: Controlled prehension and release in the C5 quadriplegic elicited by functional electrical stimulation of the paralyzed forearm musculature, Ann Biomed Eng, 8:369-399, 1980.

4. Peckham, P.H., Marsolais, E.B. and Mortimer, J.T.: Restoration of key grip and release in the C6 tetraplegic patient through functional electrical stimulation, J. Hand Surg, 5:462-469, 1980.

MAILING ADDRESS

Paul Meadows, M.S., Senior Engineer
Rancho Rehabilitation Engineering Program
7503 Bonita Street
Downey, California 90242
Voice: (213) 940-7994
FAX: (213) 803-6117

FES Exercise and Disuse Osteoporosis

Mark Malagodi, Martin Ferguson-Pell & Mary Cardi
Helen Hayes Hospital, Center for Rehab. Tech.
West Haverstraw, NY 10993

ABSTRACT

This study is examining the effects of two different electrical stimulation exercise protocols on the bone mineral density of 1-15 year post injury spinal cord injured individuals who have lost significant bone density due to disuse. The study is attempting to determine whether bone that has undergone major resorption can recover significantly. The key element being tested is the introduction of a resistive mechanical force to the exercise in addition to the forces generated by muscle activity. The results from this study will provide information that may help improvements in the design of FES exercise systems thereby reducing the rate of loss of bone soon after injury and consequently the risk of fractures when walking is attempted.

Background

Osteoporosis of the weight bearing bones of the body results from a decrease in the amplitude and rate of mechanical strain (O'Connor and Lanyon, 1982). In their studies on turkey bone Lanyon and Rubin determined the necessary mechanical stimuli to cause an increase in bone density. They showed that both the strain magnitude and the strain rate must be higher than a threshold amplitude for a response to occur. These thresholds were similar to that experienced during the turkey's normal wing flapping pattern (Rubin and Lanyon, 1985). The number of loading cycles did not need to be large. They determined that 36 cycles per day provided the maximum increase in bone, higher numbers of cycles did not have any further effect (Rubin and Lanyon 1984). These researchers also found that bone which has already become osteoporotic does increase in bone density after being exposed to these stimuli, however their increase in bone density is less than that of normal bones (Rubin et al., 1987).

This study will attempt to investigate the affect these osteogenic signals have on spinal cord injured individuals who have lost a significant amount of bone.

Statement of Problem

Within one week after the onset of spinal cord injury (SCI) the level of calcium excretion in the urine increases at least three-fold (Naftchi et al., 1980). One year after onset the bone mineral density (BMD) in a person's legs is about 50-60% of that before the injury (Biering-Sorensen et al., 1990).

In the absence of proper therapy the value of BMD stabilizes at this low level and places the subject at risk for fracture. A study by NYU Medical Center reported that 4% of patients studied had suffered a fracture from trivial and non-traumatic origin (Ragnarsson, 1984).

The onset of devices providing assistance to walking for SCI people will be unusable for patients at risk for fracture due to the increased loading during use of these devices. Therefore it is essential that proper strategies are developed to increase the strength capacity of bone thereby allowing the majority of SCI people to make use of new technology.

To date the only therapies claiming possible effects on BMD of SCI people are standing frames and the Regys 1 Clinic Rehabilitation System. Forces generated in standing frames are static and do not match the loading profile discussed in the Background section and research has shown that this method is not effective in complete injuries where there is no muscle component to complement the force profile (Wyse 1954).

The force profile during Regys exercise has a range of 0 to 1.92 lbs at a relatively low strain rate compared to walking. Three studies have concluded that after 30 weeks of Regys exercise the BMD of subjects studied did not change significantly (Leeds 1990, Mysiw 1990, Pacy 1988).

Approach

The two FES exercise systems being used in this study are the Regys 1 Clinic Rehabilitation System and an ergometer system developed as part of this study that incorporates mechanical stimuli that emulate temporal loading patterns thought to optimally trigger bone remodeling. The latter system incorporates current knowledge of appropriate stimuli for bone remodeling which will test the applicability of Wolff's Law for the recovery of bone lost due to disuse osteoporosis following spinal cord injury. This system provides exercise for the legs against a varying resistive force without compromising the aerobic benefits of the exercise activity.

Both male and female complete spinal cord injured individuals of between 1-15 years post injury with significant bone loss are currently being recruited. The subjects are distributed between the two treatment groups and a control group who receive no specific exercise beyond their normal daily activities. The exercise treatment lasts 40 weeks for each subject.

Bone mineral density is measured at 10 week intervals in the neck of femur, shaft of femur and the lumbar spine using Dual Photon Absorptiometry (DPA). Total body calcium is also measured using DPA. In addition the following laboratory investigations are performed: Ionized calcium, parathyroid hormone, metabolites of Vitamin D, bone Gla protein, calcitonin and analysis of urine metabolites.

To operate the prototype system the subject is seated in a chair fitted with a seat belt and lumbar support. The feet are strapped into ankle foot orthosis with adjustable angle stops. The orthosis are attached to sliding tracks which attach to a chain driven gear system. Under computer controlled electrical stimulation with angle sensors on each knee the legs perform an alternating leg rowing motion with the seat remaining stationary. The gear system drives a spur gear pump which causes hydraulic fluid to flow in a circuit. A proportional valve in the hydraulic circuit is fully open for the majority of strokes, but closes to a smaller orifice when the leg nears full extension during 40 cycles of the exercise session. These 40 cycles act as the low number of high impact forces required to increase bone density in the experiments described in the Background section. A force transducer in line between each track and chain connection provides constant feedback on the force the subject is experiencing.

Implications

If research on this prototype system determines that it does increase BMD, many SCI people who are currently ineligible for FES walking aids could be made eligible my undertaking a therapy program.

Acute cases of SCI could be placed in a therapy program early and thus prevent the onset of osteoporosis.

Also, the effect of decreasing urinary calcium loss for acute SCI patients could decrease the occurrence of urinary tract infection.

Discussion

Currently four patients are completing 30 weeks of exercise on the Regys system and their data are being analyzed.

The prototype system has been constructed and is undergoing clinical trials.

Acknowledgements

This work is supported by the National Institute of Disabilities and Related Research (NIDRR) Grant # H133G9014190.

References

Biering-Sorensen F. et al., (1990) Longitudinal Study of Bone Mineral Content in the Lumbar Spine, the Forearm and the Lower Extremities after Spinal Cord Injury. European Journal of Clinical Investigation. 20: 330-335.

O'Connor J.A. and Lanyon L.E. (1982) The Influence of Strain Rate on Adaptive Bone Remodelling. J. Biomechanics 15: 767-781.

Leeds E.M. et al. (1990) Bone Mineral Density After Bicycle Ergometry Training. Arch. Phys. Med. Rehab. 71: 207-209.

Mysiw W.J., Jackson R.D and Bloomfield S. (1990) Effect of Functional Electrical Stimulation Cycle Ergometry on Bone Metabolism in Chronic Spinal Cord Injury. Arch. Phys. Med. Rehab. 71: 786. (Abstract)

Naftchi N.E. et al. (1980) Mineral Metabolism in Spinal Cord Injury. Arch. Phys. Med. Rehab. 61: 139-142.

Pacy P.J. et al. (1988) Muscle and Bone in Paraplegic Patients, and the Effect of Functional Electrical Stimulation. Clinical Science. 75: 481-487.

Ragnarsson K.T. Sell H. (1981) Lower Extremity Fractures after Spinal Cord Injury: A Retrospective Study. Arch. Phys. Med. Rehab. 62: 418-423.

Rubin C.T. et al. (1987) Reversal of Disuse Osteopenia by Controlled Dynamic Loading. 33rd Annual Meeting, Orthopedic Research Society. 351.

Rubin C.T. and Lanyon L.E. (1985) Regulation of Bone Mass by Mechanical Strain Magnitude. Calcif. Tissue Int. 37: 411-417.

Rubin C.T. and Lanyon L.E. (1984) Regulation of Bone Formation by Applied Dynamic Loads. Journal of Bone and Joint Surgery. 66A: 397-402.

Wyse D.M. and Pattee C.J. (1954) Effect of Oscillating Bed and Tilt Table on Calcium, Phosphorus and Nitrogen Metabolism in Paraplegia. Am. J. Med. 17: 645.

Mark Malagodi
Helen Hayes Hospital
Center for Rehab. Tech.
Rt. 9W
West Haverstraw, NY 10993

P2.12

Intraoperative Tendon Tension and Wrist Angle Measurement System

Bertram N. Ezenwa, Mary M. Rodgers, Peter S. Barre, Roger M. Glaser, & Stefan V. Zachary
Department of Rehabilitation Medicine and Restorative Care, Wright State University School of Medicine,
Veterans Affairs Medical Center, and Rehabilitation Institute of Ohio, Miami Valley Hospital, Dayton, Ohio

ABSTRACT

This paper describes a real-time system developed to allow the objective adjustment of tendon tension during surgery. The system consists of a stainless steel buckle instrumented with force transducer, a commercially available electrogoniometer and a computer program for real time display of tendon tension and wrist angle during tendon transfer. Also provided in the software is an algorithm for predicting optimal tendon tension and wrist angle for optional wrist range of motion. Simulation studies with artificial tendon indicate that the system can be used to evaluate tendon tension and wrist angle in real time during tendon transfer.

BACKGROUND

Various pathological conditions which include rheumatoid arthritis, nerve and spinal cord injury, and cerebral palsy often require wrist tendon transfer. One of the problems which affect the success of this procedure is inappropriate adjustment of tendon tension intraoperatively. This is currently being done by subjective means because an objective real-time system for evaluating tendon tension during the procedure has not been available. Incorrect setting of tendon tension typically results in poor muscle performance and the need for repeated surgeries. The proper tendon tension would set the muscle to its optimal length for maximal force development capability. In order to develop a system for easy and rapid measurement of tendon tension and wrist angle, in realtime, the following hardware and software systems were designed.

SYSTEM DESIGN AND DEVELOPMENT

Hardware

The hardware for the tendon tension measurement is made up of the "U" and "T" sections (Figures 1 A,B) which are both constructed from hospital grade 318 stainless steel material of 2 mm thickness. When they are connected, the two sections form the tendon tension buckle (Figure 1 C). The "U" section is designed to be used to scoop up and secure the desired tendon. Provided in this section are threaded holes to match the permanently secured screws in the "T" section. This section is also provided with tendon guides near the tips of the "U" structure. These guides have a smooth

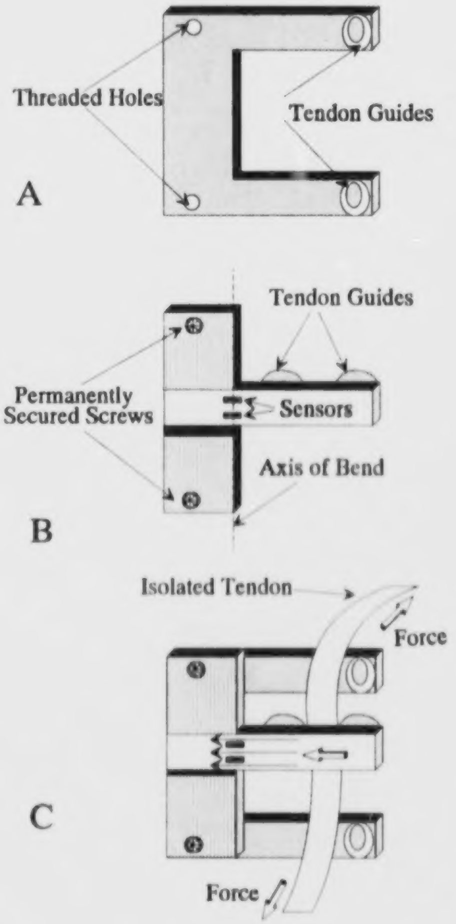


Figure 1 "U" section (A), "T" section (B) and combined system (C) pyramid shape with a flat top to secure the tendon and accommodate minor variations in tendon sizes. When drastically large tendon sizes are to be evaluated, a different tendon buckle size would be used. In conjunction with the guides in the "T" section, the guides ensure that the tendon does not slip out when the tendon is under applied force.

The thickness of the middle section of the "T" section is smaller than that of the cross section, while the cross section has the same thickness as the "U" section. Experiments with artificial tendon were used to determine the optimal thickness of the middle section and the cross section which provides accurate readout without affecting the physical integrity of the strain gauge. This design ensures that all bending tendencies are referred to the "Axis of Bend" and measured by strain gauge sensors symmetrically mounted (Figure 1B). The strain gauge arrangement is a four bridge setup uniquely positioned so that any bending moments resulting from an applied tendon tension, will be about midway between the length of the strain gauge. This section has permanently secured screws that match the threaded holes in the "U" section. These allow the screws to be turned easily to hold the secured tendon with the "U" section, but prevent them from falling off during and after the procedure. This section has tendon guides uniquely positioned so that they not only secure the tendon in place, but also ensure that the distance between the point of applied force and the bending axis remains fairly constant.

To secure the buckle, the screws in the "T" section are secured in the matching threaded holes in the "U" section after the desired tendon has been isolated and engaged (Figure 1C).

Wrist Angle Measurement System: Wrist angle was measured using a flexible electrogoniometer (Penny and Giles "M" series twin axis goniometer, Blackwood, UK). The system permits measurement of flexion/extension and abduction/adduction. This capability enables us to measure the wrist angle from +45 to -45 degrees. The system is very sensitive and capable of measuring to an accuracy of .1 degree.

Computer and Data Acquisition Hardware: An IBM Personal System/2 Model P79 386 (Boca Raton, FL) *and* *u*CDAS-16G" analog-digital (A/D) converter (Metrabyte Corp., Taunton, MA) are utilized for data acquisition and software development because of their microchannel architecture. Instrumentation amplifiers were developed to map the wrist goniometer transducer output ranging from +5 to -5 volts, and to provide a calibrated wrist angle reading of +45 to -45 degrees. Additional instrumentation amplifiers were used to amplify the strain gauge sensor signals to provide tendon tension data readings (e.g., 0-15 kg). All data are then conditioned and isolated for computer interface.

Intramuscular Electrical Stimulator: An intramuscular electrical stimulator was developed to be used to induce the contraction of muscles attached to the tendon in order to derive an active contraction profile during surgery. The stimulator consists of adjustable frequency (5-50 Hz) biphasic pulses with an adjustable pulse width of 10 to 100 *u*sec. Intramuscular electrodes (coiled fine wire) are inserted into the wrist muscles for inducing contractions via electrical stimulation.

System Setup: The system (Figure 2) consists of the buckle for tendon tension measurement, the electrogoniometer for

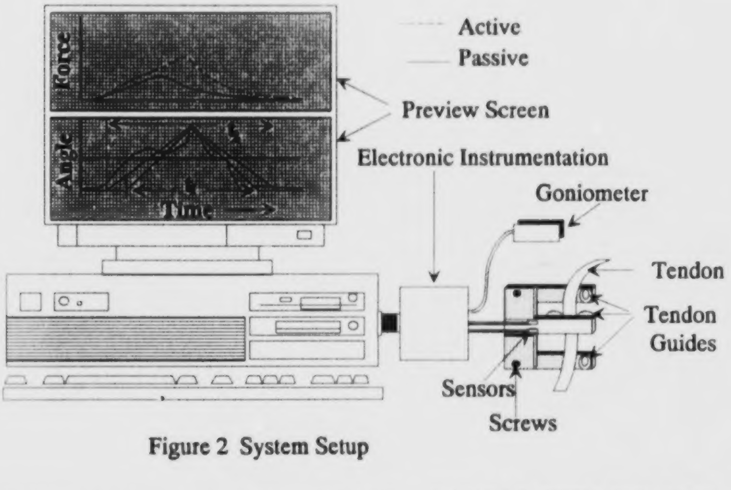


Figure 2 System Setup

measurement of wrist angle, electrical/electronic instrumentation and the IBM personal computer. The electrical/electronic instrumentation consists of the intramuscular stimulator, instrumentation amplifier for strain gauge output amplification, wrist angle data conditioning and subject isolation.

Software

The software was designed to acquire and display real-time tendon tension and wrist angle data during passive movements and/or active electrically-induced movements during surgery. The program has an option for selective data storage for predicting the optimal wrist angle and tendon tension from stored data.

This menu-driven program offers the user various windows for various optional activities described as follows. The first option is used to select a calibration file that matches the selected (size) tendon buckle, and to enter the patient's demographic data. The next option provides a split window (Figure 2) which is used for real-time display of tendon tension and wrist angle as a function of time in respective windows. This section of the program is used to provide a visual display of wrist angle and tendon tension, and to calculate the optimal tendon tension that corresponds to the muscle's optimal length and maximal force output development. Thus, this program provides several menu options which include: passive data acquisition, active (electrically-stimulated) data acquisition, display of acquired tendon tension force profile, the prediction algorithm for optimal muscle performance, and an unconditional exit from the program.

Data Collection Passive or Active: Prior to passive or active data acquisition, the user chooses the time desired to complete a +45 to -45 degree range of wrist motion (t_1 or t_2; Figure 2). This sets the graphical scale to cover the maximum possible tendon tension force during passive or active range of motion. The computer then displays on the wrist angle screen the target wrist angle profile to be tracked by the surgeon. At this point, the computer cues the user to go through the procedure while viewing all acquired data. From the observed tendon tension data, the user determines and sets an appropriate force scale. Once this scale is set, the computer cues the user to perform the passive or active wrist movements and acquire the tendon tension data. The user has the option to store or reject the data, repeat the process, acquire and store more data or go to another option.

Prediction of Optimal Tendon Tension Force and Wrist Angle. The program has the algorithm that determines any wrist angle velocity differences between the passive and active ranges of motion to assure similarity of timing. The algorithm then determines the tendon tension that is required to set the muscle to its optimal length to enable maximal force development capability. During tendon transfer, the tendon tension is set to this value at the wrist angle where maximum function is desired. This objective measurement should increase the probability for success of the surgical procedure. However, clinical evaluations are necessary to validate this assumption.

CONCLUSION

From pre-clinical evaluations using simulated tendon and wrist motion, the system appears to be usable for objective evaluation of tendon tension and wrist angle during tendon transfer surgery. These preliminary results suggest that the use of the system may eliminate the need for repeated surgeries due to inappropriate tendon tension adjustments.

Acknowledgements

This work was supported in part by the Wright State University Research Challenge Award, and by the Rehabilitation Research and Development Service of the U.S. Department of Veterans Affairs. Sincere appreciation is expressed to Bill Couch, Jose' Almeyda, Clarence Wu, and Bill Mills for their contributions to various phases of the system development.

Bertram N. Ezenwa
Dept. Rehabilitation Medicine and Restorative Care
Wright State University Research Center
3171 Research Blvd.
Kettering, OH 45420

A TWIN SIZE BED WITH FEATURES OF A CRIB FOR USE WITH THE DISABLED

Edward F. Ellingson, P.E.
Zerrecon, Inc.
Milwaukee, WI USA

Introduction

A special crib for a disabled child was designed and fabricated to meet her needs based on a regular twin size mattress and box spring. The child had outgrown the conventional baby crib but still needed the features that a crib offers, ie., protective sides and an elevated mattress level. The child's mother was highly involved in identifying the critical parameters and desired features of the crib.

Background

This project was initiated when the child's mother realized that her special needs daughter was outgrowing her crib but was not ready to go to a regular bed. She started looking for a commercial crib with a youth or twin-sized mattress but could not find one. She enlisted the assistance of her daughter's social worker, but they could still not find anything on the market. The only solution they did find was through a DME dealer who offered to add plastic sheets of the desired height to a hospital bed.

Statement of the Problem

The need identified was to design and build a twin size bed with features normally attributed to a crib, specifically,

1. High sides all around so that the child could not climb or fall out.
2. An opening feature on one side for getting at the child.
3. A mattress level high enough for ease in dressing and lifting the child out of the bed.

Design

The general design was developed in conjunction with the mother and she was requested to identify specifically the desired height of the mattress and the height of the sides above the mattress. In reviewing the design approach it was agreed that a box spring would be used initially and that the top of the mattress would be 36" above the floor. The sides of the bed/crib would be set at 19" above the mattress. As an allowance for growth, at a future date the box spring could be removed for an additional 7" on the sides, or a mattress to top dimension of 26", and a floor to mattress height of 29".

Casters were discussed and left for later application, if needed. Casters would raise the height of the bed about 2 1/2 in.

Development

The bed was fabricated from solid maple with this being used for the corner posts and panel edges, with 1/2" birch-faced plywood for the panels themselves. The birch spindles were purchased commercially and are 23 inches long.

The four sections of the bed were held together with two sets of commercial bed rail fasteners. Standard slide-bolt latches were used on the upper corners of the gate to hold it securely. The attached two photographs show the completed design.

Evaluation

The bed generally met the design expectations, but there were some problems when it was first used. It was found to that it was necessary to move the bed often, so the casters were added right away. Also, the mom must have misjudged the side height (above mattress) needed as she removed the box spring within a few weeks.

The finished design had more space around the mattress than was desired and it was necessary for the family to stuff some towels around the mattress to fill this space.

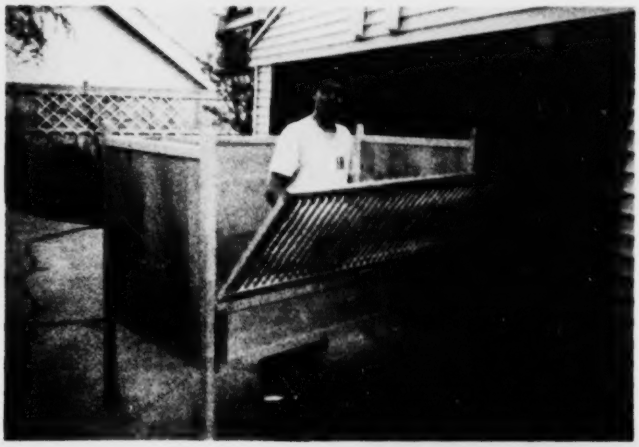
Discussion

Spindles were used on the gate primarily for aesthetic reasons but there was concern for the tapered opening that exists between spindles. Since the spindles are shaped and tapered in their design, there ends up being a tapered opening between the spindles. This could create a problem for someone who might get an arm or foot through the widest opening and then wedge it tighter and not understand what to do. It was agreed that this was not a problem for the intended user, but this should be considered in other applications.

It seems that mattress sizes do not follow an exact standard and it is recommended that the intended mattress be measured before completing the bed design.

The materials for this project cost about $250 and about 30 hours of shop labor were required.

Edward F. Ellingson, P.E.
Zerrecon, Inc.
1549 N. 51st Street
Milwaukee, WI 53208
USA



Crib at first assembly.

Completed crib and the intended user.

LIFTING DEVICE FOR CAR TRUNK TO PREVENT BACK INJURY

Edward F. Ellingson, P.E.
Zerrecon, Inc.
Milwaukee, WI USA

Introduction

A special lifting device was designed, fabricated, and installed in a car to aid a person with a back injury. The device consists of a platform that fits in the storage area and a winch unit with a lift arm that converts the pull on a rope into a lift motion on the platform. The mechanical advantage of this system could be designed at any ratio desired, or a powered actuator such as a hydraulic piston could be used.

Background

This project was initiated by a rehabilitation counselor whose client had a back injury but needed to lift devices in and out of her car trunk. The client was an adapted physical education teacher who wanted to continue her work but had a previous back injury that prevented her from lifting heavy objects. She tried to work out alternatives but it seemed that she could not entirely avoid having to move heavy equipment into or out of her car trunk.

Statement of the Problem

The request was to evaluate whether any device could help her with this lifting problem. The commercial lifting devices available were not appropriate for this problem and it was recommended that a lifting device be custom designed and fabricated to address this problem. The specification of this device was that it have at least a 3:1 mechanical advantage so that it would only take about 20 lbs. to raise a 60 lb. device, where 60 lbs. was the maximum expected weight. It was to raise the rear edge of a platform so that it was level with the edge of the trunk. This would mean that the device could then be slid out, rather than lifted straight up.

Design

A commercial boat winch with a 3:1 reduction gear was selected as the basis for the customized device. It was modified to accept a lift arm and a drive pulley, and then attached to a mounting plate. The mounting plate was then bolted to the sheet metal at the rear of the trunk and a rope attached to the pulley on the input shaft. Pulling on the rope rotated the input shaft, which in turn drove the crank arm to rise from the bottom position.

The platform was simply a piece of 3/4" plywood cut to fit the trunk area. There was also an extension piece with a piano hinge so that it was used in either of two positions, one where it was under the trunk piece such that it was hardly noticeable, and two, where it was flipped out so that it extended to the back of the cargo area. It was used this way when the rear seat of the hatchback was flipped down to give a larger cargo area and was thus appropriate for some of the larger items that have been carried.

The crank arm was designed with a roller unit from a garage door attached so that it is what lifts the platform. The roller moves across the bottom of the plywood platform as it lifts.

The attached photos show this device installed in the client's car.

Development

There was an unanticipated problem with locating the unit near the center of the trunk, so it was necessary to mount it to the side and extend the crank arm somewhat. This reduced the mechanical advantage, but a check with the client showed that forces would not be too high for her.

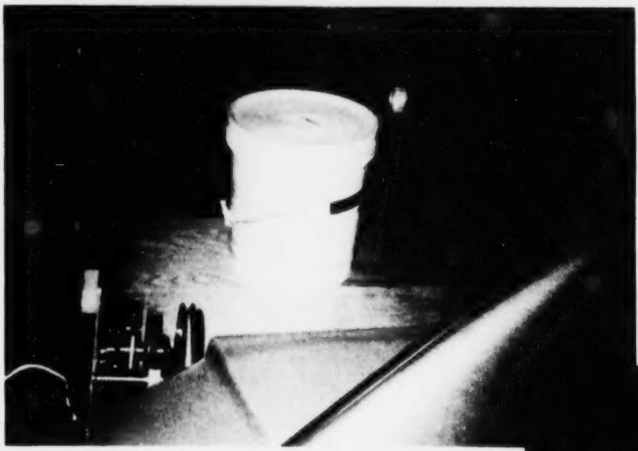
Evaluation

The lift system worked as desired and the client was pleased with the results. She had a little difficulty with some of the heavier items, but she has been able to lift every desired load and the strain on her back has definitely been reduced.

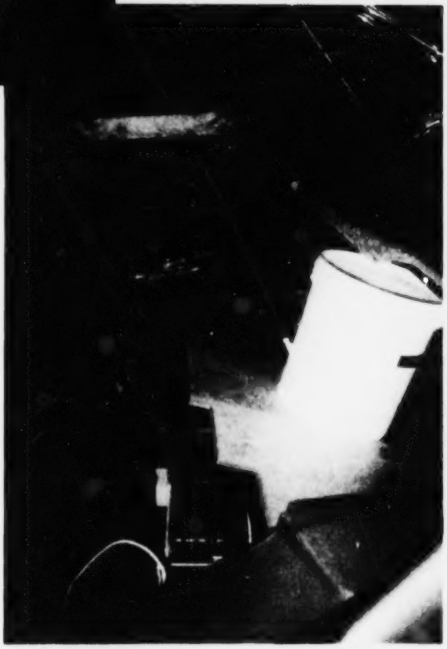
Discussion

In a more general application the mechanical advantage should be increased so that the required force would be much less; typical users would probably have less hand strength than this client. The alternative to this would be to go to a power operator with a switch control; in this way the required force could be reduced to almost zero. It is hoped that an automotive company will take an interest in this product and develop a commercial version for general application.

Edward F. Ellingson, P.E.
Zerrecon, Inc.
1549 N. 51st Street
Milwaukee, WI 53208
USA



Lift unit in the lowered position.



Lift unit in the raised position.

THE DEVELOPMENT OF A MULTI-FUNCTION VEHICULAR CONTROL INTERFACE UNIT FOR QUADRIPLEGIC DRIVERS

STEPHEN FARR, MARTIN MIFSUD, STEPHEN NAUMANN, MARGARET YOUNG.
HUGH MACMILLAN REHABILITATION CENTRE
TORONTO, ONTARIO, CANADA

ABSTRACT: A new device for controlling secondary vehicular functions is described. This multi-function vehicular interface allows for the implementation of a customized scanning strategy to be used in selecting functions, while also allowing the direct control of functions. As its modular design readily allows for a variety of input/output devices and control strategies, the interface unit offers a variety of uses as a personal controller, in addition to its intended function.

BACKGROUND: The placement and variety of controls for secondary functions such as vehicle signalling, environment control, and safety devices can impose barriers to driving a vehicle for a person with limited mobility. This difficulty can be reduced by providing control of these functions through a local interface unit that is accessed via an appropriate control strategy. A previous project (Snell et al, 1987), produced a multi-function vehicular interface unit for quadriplegic drivers. This interface unit provided the driver with access to 54 secondary vehicular controls under on-road driving conditions. Examination of this device underlined the need for a flexible, more modular system, and directly led to the development of the current device.

STATEMENT OF THE PROBLEM: In Ontario, in any one year, the Canadian Paraplegic Association estimates that 250 persons will suffer a spinal cord injury causing either partial or complete paralysis (Snell et al, 1987). Of the total spinal cord injury population, approximately 35-40% remain quadriplegic. Other causes of quadriplegia are polio, muscular dystrophy, and multiple sclerosis. Driving provides the quadriplegic person with the freedom to pursue individual goals in the community with an independence that public transportation does not allow. However, persons with limited upper limb control have difficulty accessing vehicular control functions. This difficulty can be reduced by providing control of these functions through an alternative interface unit.

RATIONALE: Commercial systems exist which allow for adaptations to a vehicle's steering, braking, and acceleration systems as well as some secondary functions. However, discussions with drivers who had used these aids indicated the need to have alternative means to access additional secondary functions since present systems cannot be adapted to provide these. Additionally, where scanning systems are used to provide access to functions, present control devices generally do not allow for the customization of the scanning strategy to the individual user's needs.

DESIGN: This interface unit was designed to provide access to up to 100 vehicular functions, either through the direct selection of the function via a discrete switch, or through the linear scanning of hierarchical groups of functions. Status of all selectable functions is presented via a labelled display screen. The basic design concept for this device was to produce a system that would allow for customization of both the input devices and the scanning strategy used to select specific functions for activation, without the need to rewrite the internal programming of the interface controller. In doing this, guidelines and models proposed to assist developers in the design of alternate access systems (McDougall et al, 1988), were followed.

DEVELOPMENT: To adhere to the chosen alternate access system model, a modular approach has been taken in both the hardware and software design stages. The scope of changes required in doing this caused us to perform a complete redesign of the previous interface system. The hardware now being used is a third-party 80C88 microprocessor package designed around the STD-bus. The software is being written in C in a style where both the structure of functions and the calling of functions meet the chosen model's guidelines.

To provide flexibility in the creation and customization of the control panel's appearance and operation, a graphics-based development system was created. This configuration facility allows for the development of the access system, the definition and placement of the input switches, and the placement of the output indicators on the finished panel. The configuration utility generates a header file which, when compiled and linked with the run-time system, provides the ROM-able code for the customized interface system.

In following these procedures our system provides for the support of a wide range and combination of input and output devices. Additionally, the operation of the unit can be enhanced with the addition of appropriate user input filters and scanning strategies. Through the use of the development system, the layout of the interface control panel and its control strategy can quickly be defined, providing the user with the control system best suited to his needs.

EVALUATION AND DISCUSSION: The project has progressed to an initial prototype that includes a 54 function display panel, a controller package with customizable software for interface control, and a configuration development system. The current stage of this project incorporates clinical evaluation of the interface under simulated driving conditions.

The modularity and flexibility of the system allows us to configure the unit to accept a wide variety of input and output devices and to optimize the control strategy. This provides us with a system that not only fulfils its requirements as a vehicular interface but also offers possibilities for use as a personal controller.

ACKNOWLEDGEMENTS: This project has been funded by the Ontario Ministry of Transportation.

REFERENCES:

1. Snell, E. et al: *A Multi-function Vehicular Interface Unit for Quadriplegic Drivers*. Report for the Ontario Ministry of Transportation and Communications, 1987.
2. Snell, E. et al: *A Multi-function Vehicular Interface Unit for Quadriplegic Drivers*. Report for the Ontario Ministry of Transportation and Communications, 1987.
3. McDougall, J. et al: *Computer-based Technology for Individuals with Physical Disabilities: Guidelines for Alternate Access System Developers*. Report for International Business Machines Corporation, 1988.

STEPHEN FARR
REHABILITATION ENGINEERING DEPT.
HUGH MACMILLAN REHABILITATION CENTRE
350 RUMSEY ROAD,
TORONTO, ONTARIO
CANADA
M4G 1R8

CALIBRATION OF IMPLANT PRESSURE TRANSMITTER

Albert C. Peng, Member of IEEE and ASEE
Wen H. Ko, Fellow of IEEE

ABSTRACT

This paper describes an automatic calibration system that can be used to determine pressure and temperature parameters of the implant intracranial pressure (ICP) transmitters [1, 2]. Although the system was designed as part of a research project aimed at studying ICP dynamic behavior and providing better patient care, the techniques and procedures used could be found useful in other applications where temperature and/or pressure characterization, compensation and instrumentation are involved.

BACKGROUND

In order to monitor intracranial pressure of patients with hydrocephalus, an ICP transmitter (8mm × 18mm × 30mm) is implanted underneath the scalp outside of the skull. Each transmitter has to be characterized to determine its pressure and temperature parameters before it can be implanted. These parameters will be used as a special data file for the corresponding transmitter so that the transmitted signal could be interpreted correctly by an external receiving system. The purpose of this paper is to present a system and algorithms that can be implemented to extract the special data file for each ICP transmitter.

RESEARCH QUESTIONS

The transmitter uses a silicon piezoresistive pressure transducer for pressure measurement. Because these transducers have a negative temperature coefficient of -3 to -12 mmHg per degree Celsius, a temperature sensor is employed to modulate the frame time (transmission period) t so that temperature compensation of the transmitted pressure signal can be carried out by the receiving system.

The ICP signal seen by the pressure transducer is digitized to a 10-bit serial datum X, which is later modulated on a 130 megahertz carrier using amplitude shift keying and then transmitted to the external receiving system via radio frequency link. The 10-bit serial datum X is a linear binary code of the absolute input pressure P applied to the pressure transducer. This relationship can be expressed as:

$$P = A + BX \qquad (1)$$

where A, in mmHg, is the pressure channel baseline and B, in mmHg per least significant bit (LSB), is the pressure channel sensitivity of the ICP transmitter. ICP can be obtained by subtracting the atmospheric pressure from the absolute input pressure P of Eq. (1). Due to the nonzero temperature coefficient of the pressure transducers used, A and B are continuous functions of the temperature T. Since the frame time t is modulated by and, thus, carries information of T, A and B are continuous functions of t as well. Leung showed that A, B and T are nonlinear functions of the frame time t [3], and they can be adequately approximated by:

$$A = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \qquad (2)$$

$$B = b_0 + b_1 t + b_2 t^2 + b_3 t^3 \qquad (3)$$

$$T = c_0 + c_1 t + c_2 t^2 + c_3 t^3 \qquad (4)$$

The twelve constants (a_0 to a_3, b_0 to b_3, and c_0 to c_3) are the temperature and pressure parameters of a transmitter. Despite the fact that all the transmitters share the same design and are fabricated using identical procedures, these parameters differ from one transmitter to another. They are the inherent characteristic data of an ICP transmitter that have to be specified and known to the receiving system before any transmitter can be used.

METHOD

A transmitter is calibrated over a pressure range of 0 to 150 mmHg above the atmospheric pressure and a temperature range of 15 to 45°C. These ranges are adequate environmental simulations for in vitro and in vivo operations of the ICP transmitter [3]. The calibration algorithms are developed based on the above four equations. At a preset temperature T, the transmission period t is measured and a negative ramp pressure is simultaneously applied to a ICP transmitter under calibration and an accurate pressure reference. Therefore, the applied pressure P and the transmitted 10-bit digital datum X can both be obtained by the receiving system. More than 50 data pairs (P and X) are collected during the entire negative pressure ramp. The baseline A and the sensitivity B at this particular temperature point can be found using linear regression [4] based on Eq. (1). The value of the actual temperature T is also acquired. Therefore, a set of data (A, B, T and t) can be obtained at each temperature point.

The above process is simply repeated at different temperatures. With a temperature step of 2°C, 16 sets of data can be collected from 15°C to 45°C. The twelve parameters a_0 to a_3, b_0 to b_3, and c_0 to c_3 in Eq. (2) to (4) can be determined from these data using cubic regression [4].

The design, implementation and operation of a computer controlled pressure and temperature source are critical to the above process. The accuracy and the cost of this source will greatly affect those of the final calibration system. The design philosophy is to develop such a source which meets the requirements of this application with a minimum cost. Consequently, commercial temperature and pressure systems which cost thousands of dollars are not considered.

For the purpose of good thermal isolation and temperature stability, a double-walled plexiglass box is constructed as the temperature chamber. Enclosed in this chamber are a temperature sensor, a heater, the cold plate of a thermoelectric cooler and an ICP transmitter to be calibrated. A fan is employed to circulate air inside the chamber in order to make the temperature homogeneous. However, only the fan blade is located inside the chamber so that the heat generated by the motor will not disturb the chamber temperature. As a result, the temperature gradient and calibration error are minimized.

The pressure system is implemented with a portable pump and two solenoid valves. One valve is used as the inlet and the other is used as the outlet. An air reservoir is added between the pump and the inlet valve so that pressure surges are filtered out. In order to prevent the pressure transducer from any damage that may be caused by over-pressure, an adjustable self relieving safety valve is utilized.

The operation of this temperature and pressure source is controlled by a HP-85 desk-top computer and some control circuitry. As a result, different temperatures within the specified range and the negative pressure ramp required can be realized automatically once the calibration process is started.

RESULTS

Approximately 15 ICP transmitters have been calibrated. This number is limited by the number of transmitters fabricated because of the cost. Since the transmitters are hermetically sealed, it takes about 30 minutes for the temperature inside the transmitter to stabilize after each 2°C change. Thus, one calibration lasts about 8 hours. The twelve parameters found for a typical ICP transmitter T85-2 are listed as follows:

a_0 to a_3	b_0 to b_3	c_0 to c_3
742.1456	0.4128533	65.4399
-11.06988	-7.26267E-4	-4.557493
0.3507978	2.687097E-5	0.1594122
-0.004203108	-3.49433E-7	-2.06715E-3

The pressure baseline A, the sensitivity B and the temperature T are plotted in Fig. 1 to 3 versus the frame time t. Fig. 4 shows the applied pressure P versus the 10-bit serial data X for selected temperature points. The accuracy of the calibration system was evaluated by comparing data calculated from these parameters with those obtained directly from standard commercial references. The maximum full scale errors were found to be ±0.8°C (±2.7%) for temperature and ±2 mmHg (±1.3%) for pressure. These accuracies are more than adequate for this application. The calibrated transmitters were also evaluated in dogs ranging from a few days to more than 70 days. Six transmitters were actually implanted in patients who required long-term monitoring. All test results indicated that the system worked successfully and was proved to be useful.

DISCUSSION

It can be found from these plots that the average temperature coefficient is about 3.17 mmHg/°C for the pressure baseline A and 0.00015 mmHg/LSB/°C for the pressure sensitivity B. Because B is almost a constant over the specified temperature range, X changes in a rate of about -8 LSB/°C to balance the corresponding changes of A. The change of X is caused by the temperature coefficient of the pressure transducer. Therefore, Fig. 4 can be used to estimate the temperature coefficient of the pressure transducer in LSB/°C.

Calibration efficiency can be improved using time-multiplexing so that multi-transmitters can be characterized simultaneously.

ACKNOWLEDGEMENTS

The authors would like to thank Albert Leung and Eng J. Sin who also worked on this project. Funding was provided by the National Institute of Health through a research grant.

REFERENCES

[1] Leung, A.; Ko, W. H.; Lorig, R. J.; and Cheng, E. M. "Design of a Two-channel Intracranial Pressure and Temperature Telemetry System.", Proceedings of ACENB 18, 1976.

[2] Ko, W. H.; Leung, A.; Cheng, E. M.; and Lorig, R. J. "Intracranial Pressure Telemetry System I: Hardware Development.", Biotelemetry Patient Monitoring, 1981.

[3] Leung, A. "Implantable Intracranial Pressure Telemeter Using Custom Integrated Circuits.", Ph. D. Dissertation, Case Western Reserve University, May 1981.

[4] Smillie, K. W. 'An Introduction to Regression and Correlation.", Academic Press, 1966.

Albert C. Peng
Dept. of Industrial and Engineering Technology
Central Michigan University
Mt. Pleasant, MI 48859

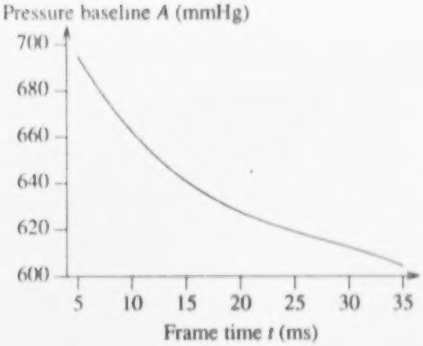


Fig. 1

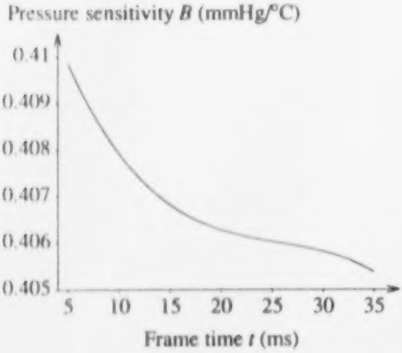


Fig. 2

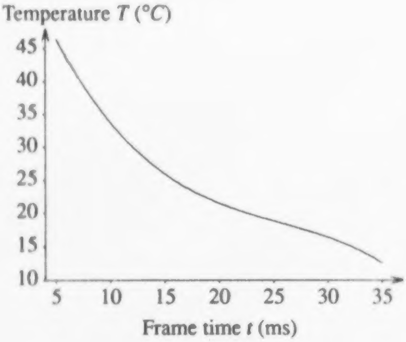


Fig. 3

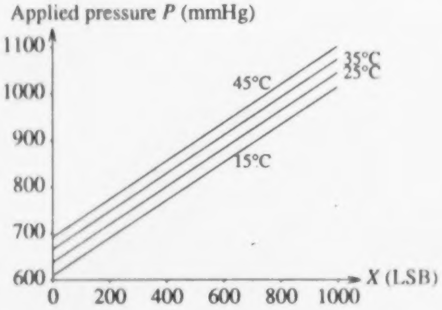


Fig. 4 Temperature effect on applied pressure *P*.

P4.2

PROGRAMMABLE INTERFACE BOX FOR SWITCHES

Andrew Y.J. Szeto, John D. Adcock & Doug J. LaRue
Department of Electrical & Computer Engineering
San Diego State University
San Diego, CA. 92182

Abstract

A reprogrammable interface box for switch control of various electronic devices has been designed and built using a low-cost microcontroller from Motorola. The interface box is highly flexible, accepts single or dual switch inputs, and can simultaneously control two 110 VAC and one 9VDC powered devices. After undergoing field tests, the interface unit will be redesigned and simplified as necessary for fabrication by high school students enrolled in electronic shops.

Introduction

United States Public Law 94-142 mandates that students with disabilities be provided appropriate educational experience in the least restrictive environment. Recent focus of this mandate has been on students that possess very limited range and strengths of movement (i.e., severe physical disabilities). A tremendous need exists to demonstrate that adaptations can allow persons with severe and profound multiple handicaps to actively participate in all aspects of community life (Taylor, 1988). For these persons, adaptations to achieve greater integration often involve the use of switches as their mode of control.

By using suitable switches and interfaces, persons with limited ranges of motion can gain control over their environment. A switch interface device interprets the user's switch actuation and responds by providing control of an electrical appliance (Szeto, et al. 1987). For example, switches can be used to control a slide projector for self-paced study; blenders for training in daily living skills; and cassette recorders and radios for instruction and/or entertainment. In vocational adaptation projects, switches and their appropriate interface can be used to adapt various employment-related equipment such as a heat gun to shrink wrap merchandise and bar-code scanners for inventory control. Depending on the particular application, a switch interface unit may provide latching for on/off operation, automatic shut-off after a pre-determined period of operation, and sequential activation of equipment in response to sequential or simultaneous closure of multiple switches. Other applications may require multiple inputs, multiple outputs, or a combination of these capabilities.

In response to this common need, a variety of switch interfaces are commercially available from many vendors. For example, Zygo (1990) sells a switch kit that contains an assortment of switches packed in a carrying case. Its catalog also lists a number of electronic interfaces that convert switch inputs into control signals for various augmentative communication devices. Asahel Engineering (1984) sells a special interface box that amplifies and converts EMG signals or thermal sensors into equivalent switch closures. Numerous switches and electronic switch interfaces are listed in ABLEDATA, a database of information on products that are useful to persons with disabilities (Hall and Vanderheiden, 1989).

Typically the user provides the switch actuation, but the control function required by the device to be controlled may vary. A latch-type function, for example, may be needed to operate a blender or a copier. For other applications and users, a time delay function may be needed to operate a heat gun or scanner for a certain length of time. Rather than make a special interface unit for each and everyone of these applications or users, we designed and built a single flexible device that could potentially satisfy many of these requirements, needing only software reprogramming to change its functionality. Such a device might find wide application for a particular user trying to control different appliances in different settings. This device would also be very useful during the assessment and customization phase of the intervention when the optimal configurations are still being explored.

Prototype Design Goals

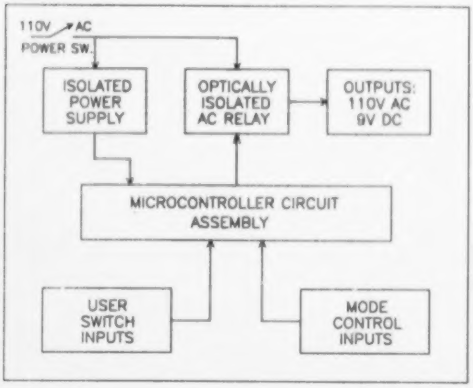
Our programmable and flexible switch interface box incorporated several popular features found in various commercially available (TASH, 1990; Ablenet, 1990) and some custom designed switch interfaces. Our design goals were as follows:

Control two 110 VAC and one 9 VDC outputs
A latched (on/off) control mode
A variable timer control mode
Single and dual switch input capability
Current limited power output power
Optically isolated output control relay
Self-contained and compact in size

The ability to control two 110V AC loads and one 9V DC load would enable a person using this device to operate up to three appliances simultaneously. The LATCH mode would turn on a device in response to an appropriate switch closure and turn off the device when the same switch was actuated again. The TIMER mode would cause the power output to be on for a specific length of time as set by a four position rotary switch. The interface box would also respond to one or two switch inputs. For dual input operation, the interface box could require that two switch inputs be simultaneously closed in order for the target appliance(s) to be turned on. Alternatively, the interface box could be set so that the two switches had to be sequentially activated. For visual feedback, an LED indicator light would illuminate whenever power was present at the outputs of the interface unit.

Technological Considerations

Once the decision was made to create such a custom-configurable switch interface, it became necessary to identify the technology that would be most appropriate in terms of cost, flexibility, ease of development, maintainability, and reprogrammability. There were essentially two choices, a Programmable Array Logic (PAL) type device or a microcontroller. PAL devices are very versatile and cost less than microcontrollers. However, they do not offer the range of functionality that could be obtained by a simple microcontroller. Since the essence of the project was to maximize flexibility of the device, we decided to pursue a microcontroller based system.



Design Details and Technical Description

The specific microcontroller we chose was the Motorola MC68HC705C8. This is a small 8-bit computer on a chip. It runs at a maximum clock speed of 4 Mhz and includes 7K of Erasable Programmable Read-Only Memory (EPROM). Having EPROM directly on the chip significantly simplifies system layout because no external data buses would be needed. The EPROM contains the operating information (or software program) for the interface, and the program can be erased and reprogrammed (using a ultraviolet light source) as necessary. This microcontroller features 24 bi-directional I/O lines, 7 input only lines, and a simple free-running timer system. A complete serial communication system is also provided on chip that could be used to access a modem or any other serial device. This microcontroller costs approximately $19.00 in small quantities and is readily available.

To achieve the desired flexibility for the programmable switch interface box, a generic circuit board was laid out using CAD programs from Accel Technologies of San Diego, CA. To handle a variety of switch-type inputs, all twelve potential inputs to the microcontroller were buffered using a pair of Motorola MC14490 chips to de-bounce the incoming signals. Microcontroller outputs were tied to power transistors which in turn switch optically isolated AC power relays.

The optically-isolated solid state DC-AC relay controlled the two 110V AC loads and a small transformer and rectifier network which provide power for the 9V DC output. An aluminum box (3"x 4"x 6") housed all the electronics.

A second transformer powered the microcontroller. The primary side of this transformer is powered through the on-off switch. For safety, the 110VAC power outputs are protected by a 10 Amp circuit breaker, and the entire device and aluminum enclosure are tied to earth ground through a three-conductor power cord. The control switches, LED, circuit breaker and power receptacles are mounted on the top of the box; the input ports (phone jacks) are mounted on its side.

Software

The Motorola MC68HC705C8 microcontroller instruction set includes "branch on bit set" (BRSET) and "branch on bit clear" (BRCLR) instructions which simplify the type of code that we needed. The program polls the input ports to establish the current status of the mode control switches, and then looks for a user switch closure. When this is detected, the program carries out the required task. The source code for the microcontroller is generated on a PC and a Motorola Evaluation Module (EVM). After the program has been fully debugged, the final program is assembled and downloaded to the EPROM on the microcontroller using the EVM. Although assembly language programming of this sort may seem intimidating at first, it is actually quite simple and can be learned fairly quickly, especially if the key command lines that control the various operating features of the interface box are known *a priori*.

Status and Future Plans

Five programmal[illegible] interface boxes have been constructed and ar[illegible]g used for various adaptation efforts. Based on these experiences, this interface box will be modified, redesigned as necessary for easy assembly, and then made ready for volume production at several of San Diego's high school electronic shops. This method of fabrication offers several practical benefits. These interface boxes would be practical electronic projects for the high school students to build. The completed products would significantly benefit other students, and the labor costs would be very low.

Acknowledgements

Funding for projects was provided by grants from the U.S. Department of Education, Office of Special Education and Rehabilitation Services.

References

1. Ablenet AccessAbility, Inc. *1990 Catalog*. 1081 Tenth Avenue SE, Minneapolis, MN 55414.
2. Asahel Engineering, Inc. *Asaflex Switch Product Brochure*. NE 820 California Street, Pullman, WA 99163, 1984.
3. Hall, M. and Vanderheiden, G. ABLEDATA and Hyper-ABLEDATA. *Assistive Technology*, 1:107-111, 1989.
4. Szeto, A.Y.J., Allen E.J., and Rumelhart, M.A. Employability enhancement through technical communcation devices. *American Rehabilitation, 13(2):8-11, 26-29, 1987.*
5. TASH, Inc. *1990 Catalog*. 70 Gibson Drive, Unit 12, Markham, Ontario, CANADA L3R 4C2.
6. Taylor, S. Caught in the continuum: A critical analysis of the principle of the least restrictive environment. *The Journal of the Association for Persons with Severe Handicaps, 13(1):41-53, 1988.*
7. Zygo Industries, Inc. *Product brochures and price list*, P.O. Box 1008, Portland, OR 97207-1008, 1990.

Andrew Y.J. Szeto, Ph.D.
Dept. of Electrical & Computer Engineering
San Diego State University
San Diego, CA. 92182-0190

DEVELOPMENT OF BATHTUB with INTEGRAL HYDRAULIC SEAT LIFT

Mary Ellen Halpin, R.N., B.S.M.E.T., Robert C. Hopely, Charles Berman
Engineering Department, Electric Mobility Corporation
Sewell, NJ

ABSTRACT

Maintaining personal hygiene is difficult for many physically challenged people. Providing access to a bathtub with a lift unit integral to the tub can help reduce some of the barriers and can help promote independence. Prime considerations of any lift unit should be safety, ease of use, and reliability.

BACKGROUND

Attaining independence is the ultimate goal of most physically challenged people. The ability to care for one's own personal hygiene is not only an important part of that independence but also one of the more difficult to achieve. The pleasures and benefits of tub bathing have long been denied to many because of the problems getting into and out of the tub. A variety of approaches have been developed to help overcome this issue, ranging from the traditional hoist to dramatic tub designs incorporating doors in tub walls. While these approaches meet the hygiene goal to some extent, there is still room for improvement by designing simple, cost-effective, and attractive alternatives.

STATEMENT OF PROBLEM

The problem of access to a bathtub is not just an issue of getting onto and out of the tub. Entry and exit should be accomplished as safely as possible. If the device is also unobtrusive and as conventional looking as possible it gains wider acceptance.

The problem is how to design a device which is both safe and unobtrusive at the same time. Many of the newer tub designs accomplish one or the other but not both.

The design should accommodate the entire household. It should be economical to install and to maintain. It should be capable of accommodating an above-average-weight person without damage or risk to the person or to the tub.

RATIONALE FOR DESIGN

The need for unobtrusive, reliable, safe methods for entering and exiting a tub led to the development of a lift unit integral to a bathtub. The seat lifting unit was designed to be used with water pressure so that electricity with its attendant hazards is not essential. The lift unit is operated by an actuator lever recessed into the tub wall; the seat can be manually rotated so that when it has been raised, transfer occurs from a seated position to a standing position outside the bathtub. No standing on a wet surface or stepping over the tub wall is required. Because this eliminates two highly hazardous conditions, the potential for independence and privacy is greatly enhanced.

DESIGN

The lift unit is integral to the tub which is a standard 32 inch by 60 inch bathtub. A molded seat fits into the tub floor and is attached to a hydraulic lifting unit that operates using standard household water pressure.

The seat and seat frame rotate 90 degrees from center for transfer; the seat can lock in place. The actuator knob is located on the inside wall of the tub and rotates through 180 degrees to any one of three positions.

At 0 degrees the seat is in the full down position. At 180 degrees the lift mechanism operates to raise the seat. The lift has 13 inches of travel and the seat can be stopped any place along the path by moving the actuator to the 90 degree stop position.

Engaging the actuator allows water to enter the system and raise the seat. When the seat is ready to be lowered into the tub, the water used to raise the seat is discharged directly into the household drain beneath the tub. The lift can be operated with or without water in the tub itself. At a household pressure of 45 psi, the lift unit can handle up to 250 pounds. Specific water pressures are frequently not determined by municipal regulation and there can be a wide variety of pressures in household systems–but the average is 45 psi.

DEVELOPMENT

In the process of developing the tub-seat lift device, key issues centered on safety, reliability, and accessibility. The safety concerns dictated a textured, flat surface on the tub bottom as well as on the seat bottom to prevent slipping, sliding, and tipping. The area around the seat is molded to allow for hand clearance;latched seat attachments to the frame prevent forward tipping if someone sits toward the front of the seat;seat locks can be installed if necessary.

In order to ensure reliability, a commercially available hydraulic bellows actuator provides trouble-free life. The tub is constructed of acrylic/ABS coextruded material on a fiberglass backing for strength and durability which makes the textured surface intrinsic to the bathtub. The simplicity of the system contributes to the overall reliability.

Accessibility is twofold. For installation or repair, if necessary,access to all piping and lift mechanism components is through a side panel. In addition, the tub-lift system is simple enough to provide right hand or left hand controls without reworking the system.

EVALUATION

The design criteria of easy access to a bathtub have been met with the lift unit. The pivoting seat eliminates the need to step over the tub wall so that many people with limitations can still maintain hygiene. The entire household is not inconvenienced since the seat is relatively flush with the tub floor when not in use. This allows others to shower or bathe without having to remove or step around a bulky or moveable device.

The textured surfaces and accessible control handles provide an extra measure of safety and privacy. The tub is standard size so that installation is relatively uncomplicated; there is essentially a one-for-one replacement with the standard size U.S. tub. The lift unit is durable and can lift an above average weight person.

DISCUSSION

Many tub aids already available are expensive, bulky, institutional-looking, or require extensive plumbing alterations. The unique patented design of a bathtub with seat lift is specifically created to fit the standard tub space with a minimum of plumbing alterations. In order to accommodate the tub space requirements with the lift unit space requirements, some tradeoff in interior water volume capacity occurred. The interior volume can accommodate an individual up to 275 pounds and a person 6 feet tall can sit in the tub with legs extended. While this does not meet every unique need, the majority of people can be satisfied.

Having a seat lift unit that is built into a bathtub provides structural integrity for the entire system. It is possible to alter the unit during manufacturing to provide hydrotherapy units, special seats, larger capacity lifting systems and still maintain rigid quality control standards. This is a significant advantage over add-on kits that can be troublesome from the standpoint of disassembling for others who wish to bathe. This built-in unit is also easier to clean since most of the exposed parts are intentionally designed for ease of cleaning.

Currently under development are modifications so that commercial as well as residential users can have motion sensor water controls installed. The implications for any individual benefitting from the Americans With Disabilities Act are enormous in terms of independent action, privacy, and public acceptance. Innovations like this tub can begin to meet the need for cost effective, reliable approaches to disabilities.

P4.4

MECHANICAL ADAPTATIONS TO PLAY ELECTRONIC MUSICAL INSTRUMENTS FOR THE PROMOTION OF EXERCISE

Jacob Apkarian, Ph.D.
Lyndhurst Hospital, Research Department
Institute of Biomedical Engineering, University of Toronto

ABSTRACT

Exercise plays a crucial role in the rehabilitation process of individuals who have had a spinal cord injury. The exercises prescribed to these patients however are repetitive and often lead to boredom. The patient loses motivation in performing them and consequently does not reap the benefit of exercise. We are attempting to address this issue using music. We camouflage the exercise by another activity, namely playing music and thus relieve the patient of boredom while performing the exercises. This is achieved by adapting the exercise devices so that patients could control electronic musical instruments via a computer.

BACKGROUND

The literature is rich with case studies where music therapy was successfully used in the rehabilitation of persons who have developmental disabilities, behavioral disorders, learning disabilities, physical disabilities, and psychiatric disorders as well as geriatrics [Bright 1980]. Over the past few decades, the evaluation methods have evolved from the anecdotal to valid scientific methods based on models borrowed from the behavioral sciences [Hanser 1987]. The benefits of music therapy can be generally divided to three categories: physical, cognitive and psycho-social. At the physical level, for example, music may be used as a means of improving gross motor skills as well as offers incentive to complete exercises which the client finds uncomfortable to perform [Hanser 1987]. At an intellectual level, music may be used to focus attention to stimuli and improve memory [Michel, 1976]. At the psycho-social level, the ability to create music has a positive effect on self-esteem, self-control and social interaction and provides for a concrete emotional outlet [Benezon 1981].

Music therapy can take one of two forms: listening to music or creating it. The latter is the form which has more potential [Alvin 1965] since it requires the active involvement of the client. In order to create music, traditional instruments must be adapted to suit the ability of the individual. To this end, therapists have devised mechanical interfaces to instruments that allow a person with specific disabilities to play these instruments [Clark and Chadwick, 1979]. Even with such mechanical adaptations, the physical limitations due to many disabilities do not allow these individuals to perform freely with the instrument and further limit their experiences to sounds produced by that instrument.

Modern electronic musical instruments can generate sounds that simulate most traditional instruments and furthermore allow for the generation of new sounds never heard before. Also, with "sampling" technology, any existing sound could be digitally recorded and transposed so that it can be replayed over an entire range of notes. Access to these instruments however is generally limited to a clavier similar to a piano.

Limited access to musical instruments by persons with physical disabilities is primarily due to mechanical constraints imposed by the "able-bodied" ergonomic design of the instrument itself. Nowadays however, electronically produced sound, whether sampled or synthesized, is easily controllable through a computer. The industry standard is the Musical Instrument Digital Interface (MIDI) which allows for communication between the instrument and a computer. Little work has been done in the field of supplying different interfaces to electronic musical instruments and publications in the field are rare. What follows is a synopsis of the work we have encountered in our search for information on the topic.

The most noteworthy effort is by a group headed by Dr. Diane Ingerham at Simon Fraser University (SFU). This group is presently in the process of developing economical MIDI based interfaces for persons with high level quadriplegia [Ingerham 1990]. This project is the spinoff of successfully completed trial projects of second year electrical engineering students at SFU. Each group of students was to design a specialized access method for a certain individual with a specific disability. The projects resulted in several successful and economical input methods which are functional for the intended client but would be difficult to adapt to others with different disabilities. For example, a stringless guitar was developed for a person who has fine control over arm movement but could not be adapted for an individual who can only move one thumb resting on a surface.

Another means of access that is being developed by a Toronto artist [David Rokeby, 1989] and primarily intended for artistic applications consists of a video camera and a computer system. Movements captured by the video camera are processed by the computer and transformed to MIDI commands transmitted to a synthesizer which in turn generates the notes. Such a system is too expensive for personal use and furthermore does not have the resolution to detect small movements in a large frame.

A group at Stanford University Medical Centre [Lusted and Knapp 1989, Knapp and Lusted 1988] is developing a system which uses electromyographic (EMG) signals from activated muscle to control sound. The use of electromyographic signals to control powered prostheses has become standard practice but no signal processing techniques exist that can readily discriminate EMG activity by more than four levels [Hogan et. al]. A minimum of seven different levels would be required however to play the range of just one octave of music. Furthermore, the generation of stable patterns in EMGs requires fine motor control, something that would be lacking in the individuals we hope to serve.

OBJECTIVE

The overall objective of this research is to create a software package and associated hardware that allows spinal cord injury patients as well as other physically disabled individuals to play electronic musical instruments using other means of input than the traditional. This paper describes a pilot study in which we adapt exercise devices used by spinal cord injury patients during their rehabilitation process so that they can play electronic musical instruments. The goal is to enhance the positive effects of exercises by prolonging their duration.

METHODS

We have developed a MIDI interface system which allows for the sampling of analog signals and the transformation of these signals into MIDI commands which in turn generate musical notes. It consists of an expansion card which inserts into the bus of an IBM PC compatible computer and a software package written in C. The card has an eight bit, eight channel analog to digital converter and a universal asynchronous transmit/receive compatible with MIDI. The software is written such that eight analog input channels can individually and simultaneously control sixteen independent MIDI channels. The input to the analog to digital converters can be derived from any circuit that produces analog output (e.g. potentiometers, strain gauges, pressure or force sensors, temperature sensors, wind velocity sensors etc.). This approach based on using analog to digital conversion allows for the use of any input device to the system and the calibration of the device to suit the needs of the user. The input devices can simply consist of potentiometers which could easily be instrumented to fit practically any joint in the body. Furthermore, sucking and puffing as well as force exertion could be easily adapted to the system. The entire system is economical and could adapt to most physical abilities.

PILOT STUDY

With the aid of an occupational therapist from the Occupational Therapy department at Lyndhurst, a patient who had low motivation levels for exercise was chosen to participate in a pilot project. His hand grasp exerciser was fitted with a linear potentiometer so that hand movement was measured by the A/D converter and used to generate music. This patient would not exercise his hands for more than five minutes. After trying the fitted exerciser, he was exercising for 20 to 25 minutes and would come to the laboratory every day to exercise. His motivation to exercise was higher and as a consequence, it is reasonable to assume, that his hand function improved at a faster rate.

We were encouraged by this response and other patients were approached to participate in the pilot project. There were several persons interested but due to logistics only two patients were chosen. The aim this time was to teach the three patients to play "Jingle bells" using the adapted devices and perform it at the patient Christmas Party at Lyndhurst. Rehearsals lasted approximately ten hours stretched over a three week period. The show was a success and audience response was positive. The patients enjoyed the experience and would like to continue. It is important to note that two of the patients did not have any previous musical training.

FUTURE DIRECTIONS

Results from our pilot study were very encouraging and our next step is to perform a formal clinical study of the potential of this approach in promoting exercise. We intend to develop a software package for commercially available hardware so that other centres may benefit from the technology. The software will include the capability of monitoring the exercise sessions to gauge the range of motion in the exercise device and the duration of the exercise sessions. These two measures will be taken while the subject exercises without and with music in order to assess the efficacy of the system in promoting exercise. We plan to adapt various exercise devices so that a variety of exercises can be performed.

Clearly, the application of this approach is not limited to exercise. Music therapy can be beneficial at the cognitive and psycho-social levels as well as the physical level. Future research will be directed at using this technique in order to promote health in other populations.

REFERENCES

Alvin, J. Music for the Handicapped Child, Oxford University Press, London, 1965.

Benezon R., Manuel de Musicotherapie, Privat, 1981.

Clark C. and Chadwick D. Clinically Adapted Instruments for the Multiply Handicapped, A sourcebook, Magnamusic-Baton, St. Louis, 1980.

Hanser S.B., Music Therapist's Handbook, Warren H. Green Publishers, St. Louis, 1987.

Ingerham D.V. and Girling D.R. Developing Economical Electronic Music Devices for Physically Disabled Musicians, Preprint , Canadian Paraplegic Association, 1989.

Knapp R.B. and Lusted H.S., A Real-time Signal Processing System for Bioelectric Control of Music, Proceedings of IEEE ICASSP, New York April 11-14, 1988.

Lusted H.S. and Knapp B. R., Music Produced by Human Bioelectric Signals, Presented at 155th Meeting of the American Assoc. for the Advancement of Science, San Francisco, 18 January, 1989.

Michel D.E., Music Therapy, Charles C. Thomas Publisher, Illinois, 1976.

Rokeby David, Personal Communications, 1989.

Hogan N. and Mann R. W., Myoelectric Signal Processing:Optimal Estimation Applied to Electromyography - Part II: Experimental demonstration of optimal myoprocessor performance, IEEE transactions on Biomedical engineering, Vol 27, No. 7, July 1980, pp.396-410.

CONTACT

Dr. Jacob Apkarian
Research Department
Lyndhurst Hospital
520 Sutherland Drive
Toronto, Ontario
M4G 3V9, Canada

Easter Seal Student Design Competition

1991 Easter Seal Student Design Competition

On the following pages you have the opportunity to read six exceptional student design papers. This year, 34 creative projects were submitted to compete in the annual Easter Seal Student Design Competition. Choosing only five winners and a runner-up was a challenge for the ten-member review panel! Yet, the papers you are about to read were chosen as outstanding examples of functional and practical design solutions. Each entry was evaluated on:

--appropriateness to user needs
--innovation and creativity
--manufacturability and marketing potential
--safety and durability
--aesthetic values
--technical competence of design
--supporting media and a working prototype

The National Easter Seal Society (NESS) made this most worthwhile event possible by providing the winners round-trip air transportation to the RESNA Annual Conference in Kansas City, complimentary room and conference registration, and a stipend for meals. Exhibit space is provided at the conference, offering a great opportunity for the winning students to share their projects and rub elbows with others involved in research and the application of assistive technology.

Who knows, this conference, and the opportunity to explore the world of assistive technology, may be the yellow brick road these creative designers were looking for!

RESNA wishes to thank NESS for its continued support of the Student Design Competition, the judging panel for a job well done, and all the students who took the time and effort to submit quality projects.

Ken Kozole, BSME, OTR
Chair
Easter Seal Student Design Competition

FUTURA TDD: Software for Baudot/ASCII Translation Modems

Norman S. Williams
Gallaudet University

Abstract

Futura TDD answers a need in the deaf community for software that works with three commercially available modems that translate between ASCII and Baudot, the code used for transmission by telecommunication devices for the deaf (TDDs). Futura features colorful screens, pop-up menus, pop-up help, and a wide array of telephone functions. The software was developed by a deaf programmer with extensive feedback from users. The software has been made commercially available at low cost, to encourage use of computers for TDD communication.

Problem

To communicate by telephone, deaf people use specialized terminals called telecommunication devices for the deaf (TDD). These devices use a five-level binary code, called Baudot, for transmission. Baudot is a slow medium (45.45 baud) that is incompatible with ASCII, a seven- or eight-level binary code used in computer communication.

In the 1980s, manufacturers of devices for deaf people began to introduce smart modems that could translate between Baudot and ASCII. Three external modems were released in the 1980s: Krown Research's SM-85, Phone-TTY's CM-4, and Ultratec's Intelemodem. These products made it possible for deaf people to use their computers to communicate with TDDs.

However, deaf people did not, by and large, begin to use these external smart modems. One barrier to their use was a lack of user-friendly, multi-function software that could take full advantage of the computer's capacities. This project sought to fill that gap in product availability.

Needs

User input was assured because the author is a deaf person and a lifelong user of TDDs. As the software was developed, deaf people were given trial versions, and the author solicited feedback and modified the software. There have been ten versions of the software since the software's release. In short, deaf people and a few hearing people who work with them have been extensively involved in the development of this design.

Users of TDDs have been accustomed to the very simple interface of existing TDDs. To use a TDD, all that one needs to do is turn on the device and begin to type. (If the device does not have a modular jack, then one must first place the telephone handset in the acoustic coupler.)

Users of TDDs have long exploited the fact that their telecommunication is visual. TDDs often are equipped with printers, for example, that allow deaf people to save conversations much more conveniently than hearing people can do with voice conversations. Printers have also compensated for the fact that the typical one-line display found on TDDs does not give much opportunity for message review; if one looks away for a few seconds, valuable information passes across the moving LED display.

Automatic dialling was available in TDDs before it was widely available in low-cost products for hearing people. Memory and automatic answering/message storage have also been available. All of these features needed to be included in software in order to make the product functionally comparable to or superior to a high-end TDD.

Because TDD users have virtually no commands to remember to begin typing their conversations, any new software would need to minimize the keystrokes and commands that would be used.

In addition to such needs, there were many more "wants" that the computer could provide to deaf people. Large number directories, for example, could be integrated in the software, and review of old messages could be very useful. Color graphics could be used to enhance the process and to make the telephone conversations more visually appealing and less fatiguing.

Literature

There has been no published work relating to software development for TDD communication, and modem development has been done by private companies, which do not publish their findings.

Given the absence of published research, the most crucial information for purposes of this study is the context in which the software was developed. As mentioned above, there are three external modems on the market. User interface software is non-existent for two of the modems, and for the other it is very limited in terms of function and ease of use. There are also two internal boards that perform Baudot/ASCII conversion. Bundled with them is software that works only with these boards. Both products have many excellent features for telecommunications by deaf users. However, they are more limited than are external modems as to the computer environments they will tolerate. For example, one of them, the IBM PhoneCommunicator, does not operate in a microchannel architecture. In contrast, external modems can operate with MCA.

Thus, the software development for this project fills a void in product availability and greatly increases the utility of several products on the market. It also may encourage the use of computers for TDD communication, a step which may move users to more widespread use of ASCII for telecommunication.

Methodology

To address the need for software to work with external translation modems, the author chose Turbo Pascal as a programming language. Turbo Pascal permits easy organization and linkage of modules in the software. It also allows for efficient use of memory.

The software was written to run with all three of the external translation modems on the market. This required familiarization with all these three products. Two of the three modems are not Hayes compatible, so that software approaches had to be tailored to the idiosyncrasies of these modems.

The user interface was modeled after ProComm Plus, because the commands are intuitive and easy to remember (e.g., Alt-H means hang up; Alt-X means exit, etc.). However, after feedback from users, pop-up menus were developed.

The software, including a directory that holds up to 500 names and telephone numbers, requires a modest 190K of RAM. Conversations are stored to disk, so that length of conversations to be saved are not constrained by memory requirements.

Features and Functions of the Software

The features of the software include:

- **Pop-up menus** allow the user to dial, look up numbers, answer the phone, and perform all other functions with minimal keystrokes. Menu selections can be made via cursor or via pressing the key denoting the first letter of the desired function. Pop-up Help screens are available from any screen.
- **Screen saver** allows user to keep computer on at all times (a requirement for a computer that must be ready whenever the telephone rings) while conserving the monitor.
- **A directory** of up to 500 names and numbers is included. The directory actually provides TDD-accessible 1-800 numbers, including those of dual-party relay services around the country.
- **Adding new numbers** and deleting numbers is done through the Insert and Delete keys. New entries are automatically filed in alphabetical order.
- **One-stroke dialling** can be done by hitting return while on the desired number. The directory can be navigated easily by pressing the first letter of the desired entry. Re-dialling and hanging up can be done with one keystroke.
- **Numbers** from the directory **can be imported** into a conversation, to avoid mistakes while giving out a number.
- **Answering** requires only one keystroke, and includes the automatic delivery of the greeting message.
- **Color** is used to differentiate who is typing in the conversation. If the conversation is printed, the differentiation is made by changing from all-upper-case to all-lower-case. The color screens are visually appealing and easy on the eyes.
- **Automatic answer** features allow the software to function as an answering machine. When a call comes in, a greeting message similar to those found on voice answering machines is given, and the TDD message is received and stored. When the user returns home and wishes to see if there were any calls, he or she need only look at the CAPS LOCK key: if it is blinking, there are messages.
- **Saved conversations** include time and date stamps, person and number called (on outgoing calls), and length of call. Similarly, during conversations, the time, date and number of minutes transpired are displayed. This is particularly helpful for controlling the length of long distance calls.

Use by the Disabled Population

The software can easily be used by any owner of any of the three external Baudot/ASCII translation modems currently on the market. Both deaf and hearing professionals find it helpful for keeping track of conversations. Dozens of people are using it already.

Futura TDD software is being made available at $50 per copy by the author. Because the result of this project is software, there is no need to transfer technology to a manufacturer. However, several major distributors of translation modems have expressed interest in the software and may begin to carry it.

Address

Norman Williams
Gallaudet University
800 Florida Ave NE Box 1742
Washington, DC 20002

A Power Wheelchair Soccer Guard Which is Quick and Easy to Use

Fred V. Tchang and Betty S. Troy
Rehabilitation Engineering Technology Training Project
San Francisco State University, San Francisco, CA

ABSTRACT

A new sport for power wheelchair users is being played in the U.S. and Canada, promising to fill a need for sport activities which involve power wheelchairs. Players of Power Wheelchair Soccer need a means of avoiding injury and protecting their wheelchairs. A quick release guard which adjusts easily was researched, designed, and tested. It protects the player and the chair and will be disabled-user friendly.

BACKGROUND

Purpose of the Project

Our original goal was to promote power wheelchair sports recognizing their potential to

1. enhance physical and mental acuity
2. motivate advances in power wheelchair design (as occurred with manual chairs)
3. provide social interactions and active play

Since there are few sports activities in which power wheelchair users can participate, we first considered developing a new one. While researching wheelchair sports, we visited a Power Soccer team in Berkeley, California and discovered a sport that is actually well suited to power wheelchair users, and had something that a newly invented sport wouldn't: enthusiastic players. It is a young sport with several teams, and we decided that as engineers, our efforts should focus on advancing Power Soccer, rather than diluting its popularity by creating a new sport.

We learned that the sport needed a protective device, a guard to protect the players' legs from collisions. It would need to be functional, durable, inexpensive, plus easily installed and adjusted by the coach, herself a manual wheelchair user.

Power Soccer Facts

Two years ago, a team was formed by the Bay Area Outreach Recreation Program (B.O.R.P.) in Berkeley. We know of only six other teams, all in Canada.

The game is based upon traditional soccer. It is played on a standard basketball court each team having four active players on the court at a time. A thirty-seven inch rubber ball is used. The two teams attempt to outmaneuver one another and get the ball through a goal.

figure 1

The Need for a Guard

Footrests of different heights result in footrests nicking the shins of other players. Safety demands that each player have a guard on his or her chair to protect the individual's legs, and to protect the footrests from breakage.

A currently used guard fulfills the needs of protecting the player and the chair. However, it is difficult and time consuming to attach and adjust. As a result, it is used only at the infrequent meets, endangering the players during the weekly practices. It consists of a plastic shield which surrounds the footrest area, attached by means of metal strips which sandwich the foot plates and cantilever forward to the plastic. Width and height adjustments are changed by moving bolts to various holes in the plastic. This leads to loose nuts and bolts which can be easily lost, and separated parts which occupy both hands. Attachment and adjustment per chair takes from two to ten minutes, depending on the chair and its accessories. Often, such accessories require tools to remove them. The process is very time consuming. A team can lose an hour of practice time just attaching and adjusting the guards. The context of these practices is parents dropping off teenagers who are impatient to play, and a coach with tools, nuts, bolts and parts that somehow don't fit into her hand. When tools are required, many loose parts exist, and a time consuming and cumbersome attachment method is used, the guards would sit in storage.

DESIGN METHODOLOGY

We analyzed the problem situation through discussions with team coaches, players, parents, and the designer and fabricator of the guard currently used. Playing the game ourselves, as well as photographing and videotaping players in action were essential elements in understanding the game and the guard's function within it.

From our analysis and research, we derived several design criteria.

Design Criteria

The guard should:

a. protect the player's legs and feet

b. prevent damage to footrests

c. prevent the ball from wedging under the footrests and causing it to tip over.

d. be able to withstand 200 lbs. of force

e. be quick to attach, remove and adjust. The attachment time is not to exceed one minute after an initial fitting.

f. have attachment and adjustment mechanisms which are "disabled user-friendly," specifically, to accommodate wheelchair users with limited trunk stability and hand grasp. No adjustment locations are to be lower than six inches off the ground. Nuts, bolts, and locks must be shaped to provide easy grip and leverage.

g. be adjustable in depth, height, width, and angle to fit most chairs and achieve a common bumping height. Additionally, the attachment mechanism must accept various tubing diameters.

h. not hamper ball handling. No player should be at a disadvantage due to the individual fit of their guard.

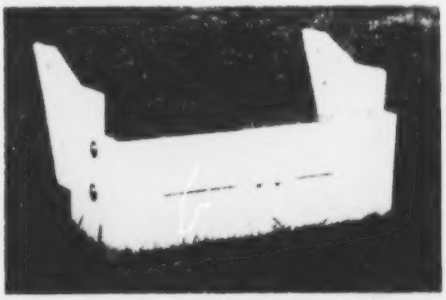
i. be suited to simple manufacturing in small numbers

j. cost no more than $ 100 each. This cost is appropriate for multiple user life, with the guard bought and retained by the sports facility or team.

k. be portable, because teams occasionally travel by airplane to meets in other cities.

THE DESIGN

figure 2



Our prototype consists of four pieces of plastic connected by carriage bolts and wing nuts (see figs. 1 and 2). The two front pieces are identical, as are the two side pieces. 3/8" thick polypropylene was chosen because it is durable, available, inexpensive, and easy to work with.

A cam-lock quick-release attachment mechanism is bolted to each side piece. The clamping blocks are cut from Aluminum bar. A v-shaped cutout was chosen to provide a universal fit in clamping onto variously sized tubes.

The footrest strut was determined to be an accessible site for attachment of the guard. It is a feature which is on all chairs and allows a higher point of attachment than the footrest plate used by the current guard.

Width, height, and depth adjustments were designed to be simple and functional. Slots paired with bolts and wing nuts are used in a system which does not require tools, but allows you to simply slide the parts to the desired dimension, and then tighten.

Angle adjustment of the guard is accomplished through two bolts at the connection point between the guard shell and the attachment mechanism. The bottom bolt acts as a pivot point while the top one can be adjusted in an arc shaped slot.

CONCLUSIONS

After testing our prototype with players and coaches, we have found the prototype guard to be:

•quick and easy to attach and adjust, requiring five minutes for initial adjustment, and thereafter, just 30 seconds to attach or remove, using the quick release cam locks.

•somewhat disabled user-friendly, with some nuts difficult to unscrew. We are evaluating alternative types of fasteners.

•excellent in adjustability of both width and depth

•adequately adjustable for height. The current adjustment site will be relocated to allow more accessible adjustment at the higher attachment mechanism.

•adequately adjustable in angle. We are refining the mechanism to eliminate the possibility of slippage due to hard hits.

•capable of good ball handling.

•efficiently manufacturable in small numbers.

•aesthetically adequate, further work will include streamlining the design and adding team colors and identity.

Overall, the prototype is more than capable of protecting the player's legs and footrests, and has adequate or better adjustability in all directions required. All production will expand with the growth of the game.

This project's long range goal is to encourage and expand sports for power wheelchair users. Our hope is that a guard which provides potential players greater safety, accommodates their chair size, and isn't troublesome, will give them the opportunity to try and enjoy this sport.

ACKNOWLEDGEMENTS

The authors wish to thank Ralf Hotchkiss, Jim Cheng, and Ronny Gaal for their guidance and support. Materials and shop-use donated by the Wheeled Mobility Center(SFSU) and Children's Hospital at Stanford REC helped make our prototype real. Appreciation goes to the coaches and players of Power soccer teams in Canada and California for answering our numerous questions and volunteering their suggestions. Special thanks to the B.O.R.P. team for welcoming us to participate in their practices. A final thank you goes to our fellow R.E.T. students.

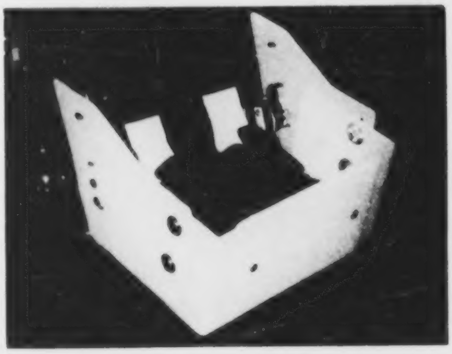
CONTACTS

Fred Tchang
372 Dolores Street
S.F. , CA 94110
(415) 621-0902

B.O.R.P.
605 Eshleman Hall
Berkeley, Ca 94720
(415) 849-3938

Betty Troy
32725 Jean Drive
Union City, CA 94587

Paul Gauthier
Canadian pwr soccer
1047 Barzalay Street
Vancouver,BC Z6E4H2



15.5

THERAPEUTIC PLAY ENVIRONMENT FOR BLIND AND VISUALLY IMPAIRED CHILDREN

Paul John Spicer, Jon Robert Salton, & Christine Hron
College of Engineering and Applied Science
University of Wisconsin-Milwaukee

Abstract

An interactive toy for blind and visually impaired children ages 6 months to 3 years was designed by a team of senior mechanical engineering students. It was decided that the "toy" should surround the child and form a total play environment containing specially adapted toys. The play environment was designed to serve as a small playroom where the child would feel safe. The individual toys contained in the play environment would encourage interaction with the environment, teach cause and effect relationships, provide tactile and auditory stimulation, and stimulate residual vision using very bright lights and contrasting colors.

Background

Adaptive toys or toys specifically designed for blind or visually impaired children are not readily available today. Ordinary children's toys rely heavily on visual feedback for play satisfaction. Available toys for blind or visually impaired children consist primarily of ordinary toys modified to be appealing to visually handicapped children. Teachers and therapists in this field have requested an exploratory toy that responds to a child's specific activation, such as reaching, touching or hitting.

Statement of the Problem

To design, fabricate, and test an interactive toy for blind and visually impaired children between the ages of 6 months and 3 years. The toy should incorporate a play activity other than visual, such as auditory or tactile. Bright lights can also be used effectively with visually impaired children.

Design

An interactive toy for blind and visually impaired children was created by designing a structure which simulated a small topless playroom. The playroom was 4 feet by 4 feet by 2.75 feet high and has a 2 foot wide opening in the front for a door. The resulting 16 square foot floor space was found to be small enough for the children to define the boundary, but still large enough to hold 3 to 5 children comfortably. The individual toys inside the environment were placed on opposite walls and at various heights to encourage scanning and exploration of the horizontal and vertical spaces. The overall height of the structure was defined by the specification that the structure must be able to fit through a standard door when turned on its side.

Five individual toys were designed to be both therapeutic and enjoyable for the children. These toys consisted of (1) a blower with moving objects, (2) a mobile play gym, (3) a radio/tape player, (4) a series of sequential bright colored lights, and (5) a textured pad that generated common sounds. The tactile, auditory, visual, and kinestetic feedback provided by the toys made them entertaining and educational. The following briefly describes each individual toy; and how the aforementioned goals were accomplished by the design. All the toys listed below were tested at the Center for Blind and Visually Impaired Children in Milwaukee Wisconsin.

(1) A toy consisting of a blower with moving objects was built into the wall adjacent to the door. The design consisted of a squirrel cage fan air blower attached to a vertical perforated transparent tube containing twelve yellow foam balls. A bright blue aluminum foil background was used to contrast the yellow balls. The tube was mounted to the inside the wall of the structure. When a child activated this toy (operated the lever type switch to turn the blower on) the foam balls were levitated and moved about in a random manner in the cavity. Air was forced through the vent holes and across the child's face, and the blower motor made a humming sound. The child used fine motor skills to control the speed of the air and the action of the foam balls. Playing with this toy helped teach cause and effect relationships, encouraged interaction with objects (the switch & air), and provided tactile, auditory, and visual feedback. The effect which seemed most enjoyable and intriguing was the air blowing out into the child's face.

(2) The mobile/play gym was mounted over the back left corner of the structure. The mobile was constructed with four

chains suspending multiple toys at heights varying from 3 to 3.5 feet. It encouraged reaching, batting and exploration of the vertical space. It also taught cause and effect relationships and gave interesting and unique tactile feedback. The toys contained on the mobile/play gym were: (1) a clear tube with rolling marbles, (2) propellers and sandpaper tubes, (3) horizontal square, round and triangular sliding blocks, and (4) hanging bells.

(3) Since visually impaired children enjoy music, a radio toy was mounted in the center of the back wall. It consisted of an AM/FM radio / tape player with a large on/off rocker switch. This switch was similar to the types of switches that a visually impaired person might encounter. Therefore, this would help children to recognize both the feel and the function of two-way switches (on and off). The other function of the radio would be to simply pacify the child occupying the activity center. The fact that the child could control the music with an on/off switch would give them the option of having it or not. The option of having a tape being played rather than just the radio added another facet. It is generally known that most children find the sound of a parent's voice to be reassuring. This is especially true with children who have vision problems. Therefore, the tape player along with a tape of a parent's voice could be used to pacify the child. Also, if a child were to have a favorite song or type of music then the tape player could be used to play it for them whenever they wanted it.

(4) A toy consisting of a series of sequential bright colored lights aimed mainly at the visually impaired children was designed. The fact that these children also like quiet and steady sounds along with low frequency vibrations promoted the effective use of a gear motor to activate four bright lights placed vertically in a clear plastic tube. A challenging activation switch was used. Not only would it be useful for a child to learn how to use this type of switch, it would also allow them to run the sequence of the flashing lights at whatever speed they desired (the play aspect). The motor that was used to activate the lights had a maximum speed of 52 rpm. This would allow the sequence of the lights to go through approximately one cycle per second. Also, the motor gave off a fairly low frequency vibration when it was running. Therefore, it was attached directly to the floor of the play environment so that it would be possible to feel its vibrations. This toy was both entertaining and challenging for all the children, and for the ones with some residual vision it was usually their favorite toy in the play environment.

(5) A textured "sound pad" was mounted to the right of the play environment's door. This toy consisted of six rectangular shaped buttons which produced distinctive tactile sensations and sounds when touched. The textured sound pad taught cause and effect and provided tactile and auditory stimulation. The usefulness of this toy in the activity center had many facets. First, it gave a sound response to a physical input from the child. Each sound was carefully chosen so that the child would not be frightened by it. The six sounds that were chosen were: a telephone bell, a bird chirping device, and four different electronic tones. This toy also helped visually impaired children enhance their sense of touch. By having a different texture on each button, the child could learn to establish a purpose for identifying different types of surfaces. Also, the orientation of the buttons with respect to each other was the same as that used in Braille writing (2 across and 3 down). Another therapeutic facet of this toy was its spatial arrangement within the activity center. The cluster of six buttons was mounted vertically toward the bottom of one wall. Younger or physically disabled children might only be capable of reaching the bottom two buttons. However, as they grew and/or developed, the fact that there are two more levels of buttons above the first enticed them to explore their vertical environment.

Development

The following safety and design goals were met with this design:
(1) The toy was caulked from the inside to prevent an electrical short in the event that a child would suck, chew, or urinate on the toy. (2) Potentially dangerous corners and edges were covered with protective strips. (3) All motors were equipped with a thermal overload switch. (4) A double screened intake vent was used to ensure a child could not get their fingers into the blower. (5) In the unlikely event of an electrical short, the toy was protected with a circuit breaker. (6) A 4 in. diameter clear cast acrylic tube was placed around the lights to prevent contact burns. (7) It was necessary to keep the volume of all

sound making toys low enough not startle a child, but loud enough to keep their interest. (8) An access door was cut into the rear exterior wall of the activity center. The location of this door in relation to the activity center itself would be on the back wall just behind the radio/tape player. The door was also placed in such a way that access to the power strip was possible. Then, if the circuit breaker in the power strip were to be tripped, it could be easily reset.

Evaulation

On December 5, 1990, the play environment was delivered to the Center for Blind & Visually Impaired Children in Milwaukee Wisconsin. The following remarks were made by four of the therapists at the center in regards to four different children. Each child had a slightly different degree of disability and the strengths and weaknesses of the environments ability to therapeutically aid the child was documented for each case.

Childs Name: Dan. Chronological Age: 2 years, 10 months. Developmental Level: 24 to 30 months. Response to Environment: "Dan loved exploring every button and switch. He loves lights and was awed by the bright display. He summed it all up himself by saying 'I like this!'" Facilitates Learning: "Dan is learning self-confidence and independence. The play environment gives him plenty of opportunities to say 'I did it myself.'"

Childs Name: Allison. Chronological Age: 3 years, 7 months. Developmental Level: 1 to 2 years. Response to Environment: "Allison loved the lights and learned to activate the switch after only 2 trials, even though fine motor tasks are difficult for her. The color contrast of the floating balls allowed her to do some visual tracking in an entertaining way. Allison also loves music and was delighted to be able to control when the music turned on or off." Facilitates Learning: "The different switches facilitate fine motor exploration and cause/effect development. The lights and floating balls are a great tool for enhancing visual tracking. The sound board can be used for tactile discrimination, auditory discrimination, memory and sequencing. Above all, they are having fun while they do all this."

Childs Name: Kyle. Chronological Age: 2 years, 4 months. Developmental Level: 1 to 2 years. Response to Environment: "Kyle is just exploring the relationship between cause and effect. The play environment gives him many opportunities to operate switches and have fun. Kyle is learning to use sign language to tell us what he wants, and we can always get him to sign 'more' when we use the play environment." Facilitates Learning: "When Kyle is using the play environment, we can enhance his visual exploration, visual tracking, communication, tactile exploration, tactile discrimination, auditory discrimination, cause/effect development and fine motor development. He's so busy playing, he doesn't even know he's learning."

Childs Name: Brianna. Chronological Age: 18 months. Developmental Level: 9 to 12 months. Response to Environment: "She was intrigued by all the toys in the play environment. We were able to facilitate use of imitative 'off' and 'on'. She spontaneously requested 'more music'." Facilitates Learning: "The design of the play environment allowed her to feel the boundaries of the unit and encouraged her to move from station to station. She can also be encouraged to use words to indicate her choices for play activities."

Discussion

The culmination of this project gives a fairly clear indication that the play environment design was successful. While none of the individual play environment toys by themselves could assist a child in all of the areas mentioned (visual, tactile, auditory, cause/effect, etc.), the play environment as a whole did achieve these goals. Also, the fact that this unit was designed with blind and visually impaired children in mind does not mean that they would be the only group of children who could benefit from it. The play environment would be effective for children of all abilities as long as their age fit the range of skills that are required (to 3 years).

Reference

Center for Blind and Visually Impaired Children, Inc. 3722 S. 58th Street, Milwaukee, WI 53220. 414-464-3000.

Financial Supporter: Edward F. Ellingson

Paul John Spicer
3107 Doris Lane
Appleton, WI 54911

Tomorrow's Chair: A Device to Facilitate Sitting and Standing

Kristen R. Morrow
Dartmouth College - Class of 1992
Hanover, New Hampshire

Introduction

A New York Times article of January 22, 1991 details how the US government is setting stricter regulations with regards to handicap accessibility. The government recognizes the many obstacles that prevent the handicap and elderly from performing fundamental daily functions, i.e. shopping, banking, and working. (Ref. 1) Beyond the scope of the U.S. regulations are a whole realm of additional obstacles for the those with poor mobility. This project concentrates on eliminating an obstacle and facilitating an action fundamental to movement, standing from a sitting position. A new chair prototype is developed through careful engineering analysis. Ergonomic data and the forces generated by a person's weight determine the specifications of the device. Many alternatives fit these specifications. The final design is a simple frame chair that rocks the user forward as their body weight is transferred. Once forward, the chair remains in position to allow the easiest egress to a standing position. The design is a user-friendly, comfortable, technologically sound device to assist the disabled to stand from a sitting position.

Problem

For years, my grandmother has struggled to lift herself out of a chair. She has a stiff right leg, an injury incurred in a car accident at age seven, and problems with her left knee. Movement from a relaxed sitting position is a problem for many elderly and handicapped. The nature of the common chair is to position the user's weight in the back of the seat thereby relieving the legs from forces. The act of standing up demands the transfer of the user's weight from the back of the chair to the legs. This transfer puts a large stress and demand of the knees and/or arms to lift the body.

The solution, an improved chair, is designed to treat the difficulty as a technical problem. An effective chair must facilitate the user's movement. The solution is a design that benefits the user's attempts to sit and stand.

Methodology and Development

Before beginning the design of a solution, general specifications for the device are generated. The most important specification is that the chair must allow the occupant to sit and stand with ease. This function may not require any power source, but must be inherent in the mechanics of the design. For comfort, the design must be relatively stable and comply with the appropriate anthropometric and ergonomic data. (Ref. 2) All geometric specifications are controlled by the user's body dimensions, i.e. the length of the thighs, extension of arms and height of calf and knees. The size shall stay within the limits of a four foot cube. The finished design must be simplistic and aesthetically pleasing.

Some alternatives solutions are generated through brainstorming. One possibility is a spring-loaded design that counteracts the weight of the user. Another model transfers the force on the armrest to lift the back edge of the seat. A third alternative is a chair weighted at the front of the seat which pivots about the connection to the armrest so that once the user's weight is lifted off the chair, the seat will provide a gentle force on the back and the upper thighs. Small pressures generated by the legs can be optimized by a design where the seat rolls back away from the user. A modification of the mechanism in an office chair would allow the user to tilt forward in order to get up. The last alternative, transfers the body weight by rocking the occupant in and out of the chair. All of the alternatives utilize a balance between the weight of the chair and the weight of the user. In addition, all of the designs have armrests. The armrests allow a major part of the force necessary for standing up to be generated by the person's arms. The designs also include contour seats for comfort.

In the analysis of these possibilities, the needs and desires of the user are considered. All of the alternatives facilitate sitting and standing. The differences lie in the nature of the help provided. Some of the choices are too forceful and intimidating. The aim is to avoid any unanticipated motions. The user should be comfortable with the movement, not hurled from the chair. Any alternatives with those characteristics are therefore unacceptable. A slow, even process is most comfortable for the elderly and the handicapped. It allows them to remain in control of all movements. From the preliminary evaluation of all the alternatives, two designs are most promising and pursued more in depth.

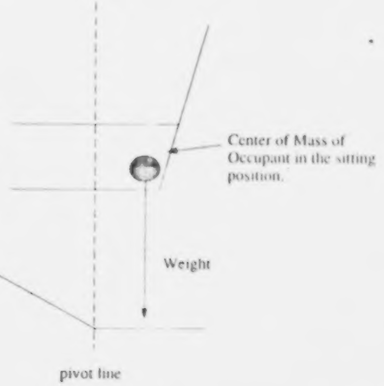
Further experiments are performed on the modification of the office chair and the rocker design in which working models for both designs are assembled. In an office chair the tilting mechanism is rotated 180° degrees to allow the chair to tilt forward rather than back. The hinge is centered width-wise on the seat and moved along the length of the seat experimentally to determine optimal placement. The intent of the modification is to transfer a force exerted by the user's legs, in order to lift the back of the seat and help the occupant out. Testing reveals that lifting the back of the seat, however, requires a great amount of force. In order to lift the back portion to a desirable height, the pivot point is placed close to the front edge of the seat. The placement greatly decreases the mechanical advantage of the person applying the force. Since the moment arm is smaller, the force applied must increase proportionately in order to generate the torque necessary for rotation. The force requirement is considered a flaw in the design. It is projected that the targeted users could not generate the necessary forces for an effective use of the chair. Therefore, emphasis is placed on the rocker design.

A wooden model of the rocker is built. In order to allow for experimentation, the rockers are detachable and adjustable in relation to the seat. Early observations reveal that the problem of large force requirements in the office chair design is eliminated in the rocker design. The height placement of the point of rotation increased the effectiveness of the chair. Since the pivot point is at a greater vertical distance from the seat, the angle of inclination increases in relation to the vertical displacement of the seat back. More importantly, however, the rocker uses the redistribution of the body weight to the occupant's advantage. The force necessary for rotation is provided by the body weight. By shifting their center of mass beyond the pivot point, rotation occurs and the chair rocks forward to a position that facilitates standing up.

In order to insure stability and an inherent feeling of control for the user, the rocker is a two-plane system. In the sitting position, the chair is comfortable with a slightly reclining angle and does not rock. (See Figure 1.) The rocking occurs as the user shifts their center of mass beyond the pivot. (See Figure 2.) At this point, the chair rotates onto another stable plane which gives the user a better angle for standing up, while providing a stable resisting force for the pressure of the arms on the armrests and frame.

After establishing the rocker as an effective design, the specific elements are more carefully analyzed. Being the most complicated and most important element of the design, the rocking plane is examined first. From calculations regarding the size of the legs, a preliminary angle of 30° to the horizontal for the front plane pitch is chosen. In experimentation, however, this angle proves too severe. A smaller angle of 10° is the most effective. It allows the user to shift pressure onto the legs and to situate themselves in a position where standing is facilitated. The determination of the position of the change in planes, the pivot point, incorporates the anthropometric dimensions of the thigh and center of mass. At the desired position, the occupant's conscious shift in his or her body weight, will rotate the chair to a front plane. For a seat of depth 17", the ideal position is 10" from the front, 7" from the seat's back edge. With the pivot point deeper (further from the front) than 10" normal reaching movements could cause the rotation. At positions beyond this ideal in the other direction, it is more difficult to shift the center of mass. The curvature of this pivot point has two contradictory repercussions. If the pivot point is a simple straight line angle of 10° the rotation is quick. On the other hand, if there is a curve, it is possible for the chair to rotate without a conscious effort by the occupant. Since the latter action is considered a bigger problem, the transition remains fairly brisk as the pivot maintains an extremely large radius of curvature. The length of the rocking plane is preferably just large enough to support all forces. Excess length can be a tripping hazard. The final length of the rocking plane allows for stability in both positions. In the back position the rocker does not exceed the back of the seat, and in the forward position it ends directly at the normal from the end of the armrest to the ground plane.

FIGURE 1



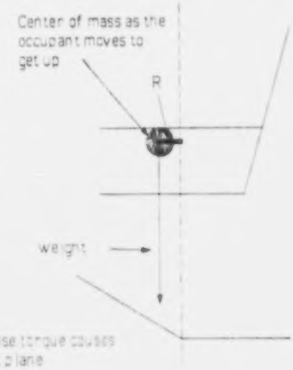
After analyzing the rocking plane, the focus shifts to defining its interaction with the other elements of the chair. The contour of the seat derives from experiments with a chair machine. The original seat contour has a back angle of approximately 15° to vertical. In addition, a rise in the front of the seat supports the knees. Due to the specific handicap of the case study, (a stiff right leg), the original raised portion of the seat decreases, thus allowing the stiff leg to rest more comfortably on the seat. Careful attention is given to avoid discomfort between the seat bottom and the seat back. A large radius curve connects these two portions providing maximum comfort. The orientation of the seat relative to the rocker delineates the mechanical integrity of the design. The seat is to be comfortable for normal relaxation usage, while on the other hand, it is imperative that the seat angle gives support to the legs as the occupant stands. In the siting position the front of the seat is above the horizontal whereas in the entry and exit position it is below the horizontal. Therefore, while relaxing the chair eases stress on the legs, and when the user moves to stand the legs are in the position of thigh above knee.

The armrests are the final element considered in the design. When the seat is in back position the armrests are 25" above the ground plane, thus establishing the armrest approximately 8" above the seat with slight variations along the seat length. Therefore, the user's arms rest comfortably when sitting. In addition, the height of the armrests allows them to provide a steady resistance against which the user can push. The length of the arms and the nature of the downwards forces applied when standing up, stipulate that the armrests span the length of the seat. The weighted balance of the chair controls the stability of the armrests. The chair is balanced so that only an outside force can cause rotation. In other words, the chair remains in the forward position (after the rotation by user), so the armrests provide a solid resistance. The armrests are a width design to fit the hand comfortably and foster a natural, easy grip, approximately 11/2" to 2".

Prototype

After performing the engineering analysis above on the working model, a prototype design develops. The geometrical parameters depend on the anthropometric data of the user. In order to provide the desired benefits, the height of the chair must change with the height of its user. Analysis of the ergonomic data reveals that in order for the user to receive the benefits of the chair the height must be

FIGURE 2


Center of mass as the occupant moves to get up
R
weight
Counter-clockwise torque causes rotation to front plane

increased commensurate with the increase in the length of the calf. In other words, for every inch increase in the size of the lower leg, the front height of the chair should be increased one inch. (The starting height is 17" for a model user 5'5" tall.) Due to this fundamental qualification, the prototype is custom designed to fit the needs of the model user (Female 5'5" tall).

The combinations of the necessary structural elements generate several different designs for the prototype. The prototype design is chosen for is chosen for its simplicity and elegance. The prototype integrates two wooden frames with a contoured seat. The frames compose the armrests, structural supports and bottom rocking plane. The seat is supported in two places by the wooden frames. Cabinet fasteners are used at the connections. Thin sheets of plywood form the seat. The plywood sheets are glued and molded to the contoured form using a vacuum bag to apply constant, even pressure. The right and left frames are cut and shaped of ash wood. A wooden dowel along the bottom of the rocker increases the left to right stability of the chair. As an element of the aesthetic design, the dowel's circular shape delineates the point of rotation. In addition, foam and upholstery cover the wood seat for additional comfort.

Conclusion

Presently, the prototype is functional. It provides a solution to the problem of lifting oneself out of a chair - a problem daily experienced by many elderly and handicapped. In particular, it is custom fit for the needs of my grandmother, Rose Casolaro. The height and other dimensions are suitable for the her height (5' 5"). It allows her to use her stiff leg to balance and to carry a portion of the load necessary for standing. Moreover, the design provides a helpful hand. My grandmother observes the support of the chair on her back and stiff legs as she sits. In addition, she feels the chair helps her stand and sit while maintaining control and a comfortable pace.

Often designs to fit the same purpose would combine complicated mechanical and electrical parts that are not user friendly and are often intimidating. The rocker chair presented here is not a complex piece of machinery, it is something that looks natural in a living room setting. In addition to being a great help in the home, the design would be useful in doctor's offices, nursing homes and similar facilities. Patients using these chair would have more freedom in their movements, and require less assistance. This user-friendly chair is a technical solution that combines engineering analysis with aesthetic simplicity. This is how devices for the handicap should be developed!

Acknowledgements

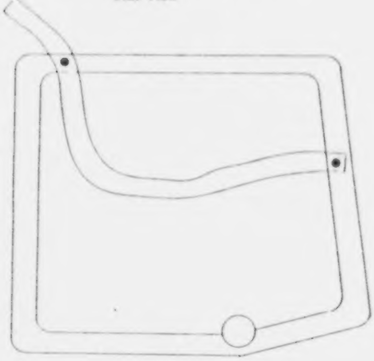
Funding for project provided by the Thayer School of Engineering at Dartmouth College. Special thanks to Professor Francis Kennedy, Peter Robbie, the Hopkins Center Design Studio, and Roger Howes for their assistance.

References

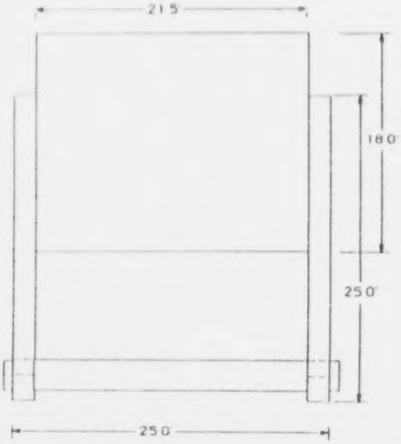
1. Pear, Robert. " U.S. Proposes Rules to Bar Obstacles for the Disabled." New York Times, 22 January 1991, sec 1, p. A1.
2. Diffrient,Niels, Alvin R. Tilley, Joan C. Bardagjy. *Human Scale 1,2,3.* MIT Press. Cambridge, Massachusetts. 1974.

Kristen R. Morrow
21 Birchbrook Drive
Valhalla, New York 10595

Final Prototype Design
Side View



Final Prototype Design
End View



16.10

A PORTABLE, TRUNK-SUPPORTING TOILET SEAT

Raymond L. Grott and Elaine M. Westlake
Rehabilitation Engineering Technology Training Project
San Francisco State University, San Francisco, CA

ABSTRACT

The goal of this project was to provide a young girl with cerebral palsy with a portable, trunk-supporting toilet seat adaptable to fit securely on any toilet encountered in residential, institutional or public settings. The resulting design reflects the challenges presented by a wide variety of toilet shapes and sizes together with the complex physical, social and emotional needs of the client and her family. In addition, the current design provides a stock base assembly upon which specialized seating surfaces can be mounted to accommodate a wide range of client needs and sizes.

INTRODUCTION

Neuromuscular disorders or paralysis often leave a person with weak or uncoordinated muscles and the inability to maintain a stable seating position without physical restraints or assistance from another person. Resulting issues of self-reliance and personal dignity are compounded when assistance is needed in using the toilet.

Our 8-year-old client, Ana, has severe athetoid cerebral palsy. She cannot sit independently and utilizes a sturdy commode chair with a lap belt at home so her family members or attendants can leave her in privacy during elimination. When travelling beyond the house, the commode chair must go with her, usually in the family van—a cumbersome process. If this is not practical, she must be supported by another person. Furthermore, Ana tends to exhibit pelvic thrusting caused by increased extensor tone at the hips, compounding her difficulties when sitting in her commode chair. Ana's family is very committed to her independence, dignity and self-esteem. They requested a trunk-supporting toilet seat attachment that was compact and portable enough to be carried on the back of her electric wheelchair.

DESIGNING FOR THE WORLD OF TOILETS

A product search utilizing Abledata, Pro-Find and professional therapists revealed a few support seats on the market. However they all relied either on a system of bolting to the toilet (not portable) or a chair-like superstructure (too bulky) for stability and safety. A comprehensive U.S. Patent search from 1960 to the present failed to uncover any useful designs that might not have been marketed. It was noted that both portability and stability were designed for in some high-rise toilet seats. Unfortunately, none could fit every toilet. When a significant degree of variation in toilet styles was provided for, adjustment was accomplished by changing bracket sets or by multiple adjustments with a wrench.

The design team measured the dimensions of over 40 models of toilets in a variety of locations, both those in place for many years as well as the latest "designer" models. The following design criteria were established:

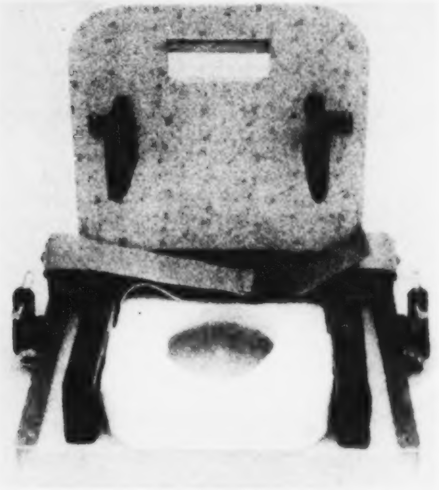
1) **Use of the toilet bowl as a stable seating surface rather than the seat.** Due to the inherent looseness in toilet seat hinges and the current use of plastic hinges and bolts.
2) **Utilize points of attachment on either side, 9" back from the front edge of toilet bowl.** Despite the wide variations in shapes and sizes, one dimension, the width near the centerline of the bowl, varied the least (from 13-1/2" to 15").
3) **External rather than internal clamping.** Reflects considerations of the questionable cleanliness of public toilets and the generalized aversion to the internals of plumbing fixtures.
4) **Avoidance of architectural barriers.** The absolute maximum horizontal extension of any part of the device is to be 15", measured from the centerline. This is the clearance created by compliance with the Uniform Plumbing Code.
5) **Durable.** Mechanisms to minimize contact with and resist corrosion from water and urine.
6) **Safe and secure.** A testing rig was constructed and subjected to static and dynamic conditions with weights of 65 and 155 lbs (Ana weighs 40 lbs) to determine the potential stresses on the seating base and back and the forces tending to tip the assembly off of the toilet bowl. Measurements were made for forward sliding, backward tipping and side leaning. The results were established as construction guidelines.

DESIGNING FOR THE USER

The design team met with Ana and her family to examine her needs, evaluate her existing commode chair and incorporate their input and ideas into the design. The resulting design parameters were:

1) **Provide an "anti-thrust" adaptive seat and lateral hip bolsters.** Significantly reduces hypertonal extensor thrusting which can greatly impede elimination. (See references.)
2) **Provide a firm back with lateral trunk supports and a padded lap belt.** Ana has a tendency to lean forward or to either side.
3) **Adjustability for size and growth.** The seat, lap belt, back location and lateral trunk supports are to be adjustable or replaceable.

4) **Ease of use.** The device should be simple to operate and easy to explain, as a wide range of people might be called on to help Ana use it. Minimal strength should be required.
5) **Sanitary.** The device will have a "clean" appearance and coverings will be made of materials that can be easily washed or wiped down.
6) **Friendly design.** Not antiseptic or institutional. Ana should "like" the device and participate in aesthetic choices.
7) **Collapsibility/portability.** The device should fit on Ana's wheelchair (19" X 23" available on the back) and weigh under 15 lbs. Back support to be removable to aid cleaning and manipulation.
8) **Reasonable price.** Although the family will not be charged for prototype work, the issue of affordability for other users was considered.



DESCRIPTION OF THE SEATING DEVICE

After several design efforts, with input from faculty advisors, fellow students and Ana and her family, the team constructed a working prototype. Its key elements are:

Universal Base. A simple rectangular flat base of 3/16" acrylic plastic, hot pink (Ana's choice), 18" wide (to accommodate the largest toilet and mechanisms) by 14-1/2" deep (limit set by smaller-dimensioned toilets) with a 2" lip on front and back sides. One-eighth inch thick aluminum angle stock was attached to the side edges for strength. The receptor for the back support is mounted to metal brackets (adjustable on the base for growth). The lap belt anchors to these brackets.

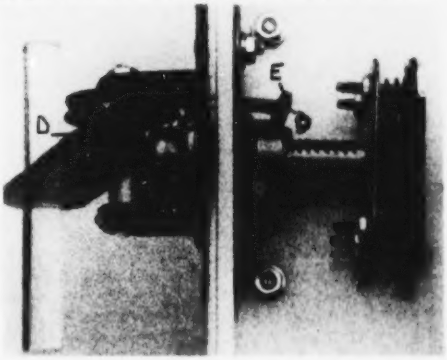
Custom Seating Insert. An anti-thrust seat and lateral hip bolsters were constructed of dense polyethelene foam and covered with grey and pink vinyl materials. The seat matched the specifications of Ana's wheelchair insert designed at Children's Hospital at Stanford.

Removable Back Support. Constructed of 1/8" plywood with a light-weight hollow-core design. A latching mechanism was built into the back, locking the base upon insertion into its receptor. Compression of a lever in the hand-hole at the top releases the back. Padded lateral trunk supports which fold flat for compactability are affixed.

Base Attachment Mechanism. The defining design requirements were safety and reliability. This required the application of a consistent, repeatable, predetermined gripping force to the sides of the toilet bowl, regardless of toilet dimensions or user strength. Simplicity of operation was also a priority

A resilient rubber pad, chosen for its high coefficient of friction on both dry and wet surfaces is attached to a spring-loaded backing plate (A) (Pre-load on springs is adjustable for prototype testing). The pad and backing plate is fixed to a spring-activated piston (B) which can travel horizontally in its housing (C) to accommodate varying widths of toilets. The piston can be made to lock in its housing while an eccentric cam (D), attached to a hand-driven lever, pushes the housing assembly inwards towards the toilet a fixed distance.

Operation is as follows: [1] The base is slid towards the back of the toilet. (Pads on each side travel with the piston to maintain contact with the toilet rim.) [2] As each lever is lowered 20 degrees from full upright, tension is released on a pin (E), locking the piston in its housing. [3] Further rotation of the lever arm and eccentric cam pushes the housing/piston/pad assembly towards the toilet, compressing the pad springs and exerting a pre-set force of aprox. 25 lbs per pad. [4] Lever self-locks in downward position. [5] Return of lever to full upright releases mechanism for removal of base.



Completed Device: Weighs 11.5 lbs, is 21-1/2" X 14-1/2", 6" thick when collapsed for carrying. Maximum extension of lever horizontally is 13" from centerline.

TESTING OF PROTOTYPE

Once constructed, the prototype was tested for fit on several styles of toilets and subjected to force tests similar to those done on the test rig. The device successfully withstood the specified loads.

The seat was then delivered to Ana and her family for testing. The initial trial was quite promising. The device installed easily, remained firmly in place and appeared to inhibit or reduce Ana's thrusting behavior. The users were enthusiastic about both the performance and the appearance of the device. Minor adjustments were made and the family is continuing to test the prototype.

FURTHER WORK

After a test period, the team will construct a final device for delivery to the family. This will incorporate their feedback from testing, better seat coverings, a more carefully-machined mechanism (enclosed for appearance and cleanliness) and a carrying case.

The design team plans to explore other potential categories of users and their requirements for specialized seating.

The team is aware that the built-in toilets used in most airplanes and trains will not accommodate this portable toilet seat or most other assistive devices. This and other access issues with these toilet facilities can best be resolved by the travel industry.

MANUFACTURABILITY

This prototype was constructed from readily-available materials using simple shop equipment and techniques. Materials used cost less than $50. While the mechanical concepts employed are basic ones, the structure and mechanism can be further refined and tailored to manufacturing methods.

Production of the standardized base in quantity at reasonable prices should be feasible. It is expected that the price would fall within the range established by Columbia Medical's (bolt-on) support seat which sells for $250 in the child-size version.

The cost of custom adaptive seating inserts would vary depending on individual needs.

MARKETABILITY

The design team feels that a noteworthy feature of this project is the development of a stock mounting base to which customized adaptive seating and back supports can be attached. Design considerations, while prompted by the particular needs of Ana and her family, are believed to be widely applicable.

People with disabilities, therapists, medical equipment suppliers and other interested professionals consulted have stressed to the team the need for a portable, trunk-supporting toilet seat. This seat could meet the needs of a wider market, increasing independence and access to community activities, recreation and travel for many.

REFERENCES

Seikman, Allen R., Flanagan, Kelly. "The Anti-Thrust Seat: A Wheelchair Insert for Individuals with Abnormal Reflex Patterns or Other Specialized Problems."Proceedings of the RESNA 8th Annual Conference, San Diego, CA, 1983, 203-205.

Seikman, Allen. "The Anti-Thrust Seat, A Ten-Year Retrospective." Rehabilitation Engineering Center, Children's Hospital at Stanford, Palo Alto, CA, 1988.

ACKNOWLEDGEMENTS

The design team wishes to acknowledge the assistance of Dwight Johnson of VIVCO, Professors Ralf Hotchkiss and Peter Pfaelzer along with fellow graduate students in the Rehabilitation Engineering Technology Training Project at San Francisco State University. We especially appreciate the time, support and cooperation of Ana and her parents, Judith and Cy.

CONTACTS

Raymond L. Grott
102 Hamilton Place
Oakland, CA 94612
(415) 835-5815

Elaine M. Westlake
10 Guy Place
SanFrancisco,CA 94105
(415) 495-1958

Author Index

Abbott, S., 55
Ackroyd-Stolarz, S.A., 356
Adams, K., 55
Adcock, J.D., 414
Aisen, M.L., 248
Al-Temen, I., 154
Allaire, J.H., 320
Alm, N., 107, 311
Amori, R.D., 323
Angelo, J., 88
Antczak, J., 154
Apkarian, J., 420
Armstrong, W., 344
Arnott, J.L., 105, 311
Ashlock, G., 61
Ault, H.K., 33
Aylor, J.H., 234
Backlund, L., 44
Baker, L.L., 289, 388
Baker, B.R., 112, 263
Baldwin, J.D., 237
Balfour, L., 154
Ball, J.E., 210
Barnicle, K., 30
Barnicle, K., 283
Barre, P.S., 402
Bass, C.L., 222
Belbin, G., 361
Berman, C., 417
Berube, N.L.J., 248
Betz, R.R., 394
Bobanovic, F., 277
Bogue, T., 367
Boonzaier, D.A., 176
Booth, L., 105
Borenstein, J., 10
Boyless, J.A., 36
Bradley, R.H., 219
Bradley, W., 210
Bristow, D.C., 306
Britell, C.W., 48
Brongo, D.M., 128
Broumley, L., 107
Brown, C., 341, 383
Brownlow, N., 160
Burnett, J.K., 48
Burnfield, J., 388
Burrow, M., 300
Byun, H., 234
Campbell, J., 274, 286, 391, 397
Cannon, T.W., 231
Cardi, M., 399
Carter, C., 274, 286
Casement, D., 344
Cavalier, A., 341, 383
Caves, K.M., 166
Chambers, R.B., 388
Chan, L.W.Y., 46
Cheng, P.K., 53
Churillo, F., 151
Clark, M.C., 4
Coltellaro, J.J., 266, 333
Cook, A.M., 82, 266
Cook, G., 367
Cook, H.W., 181
Cooper, R.A., 82, 240, 245
Cox, G.L., 74
Craffey, S., 370
Cremaldi, E.R., 7
Cress, C.J., 257
Cronk, S., 199
Daggett, G., 335
Danis, C., 335
Davis, R.B., 370
Demasco, P.W., 97, 109, 210
DeMuth, S., 388
Dominguez, L., 222
Dunaway, J., 210
Dzielinski, C., 370
Elger, G., 44
Ellingson, E.F., 405, 407
Elting, S.E., 72
Epstein, E., 335
Evans, D.K., 50
Evers, M., 286
Ezenwa, B.N., 292, 402
Fagerberg, G., 23, 44
Farr, S., 409
Fee, Jr., J.W., 121, 131
Ferguson-Pell, M., 399
Field, W.E., 181
Field, D., 373

Fleming, B.P., 58, 381
Ford, K., 330
Ford, M.R., 146
Foulds, R.A., 38, 314
French, G.J., 257
French, J.J., 376
Fridie, S.E., 193
Friedman, M., 333
Friel, D.C., 386
Frische, E., 341
Furugren, B., 44
Galuska, S., 38
Gammie, A., 21
Gaster, L.S., 79
Gellman, H., 397
George, C.L., 58
Glaser, R.M., 292, 402
Glennen, S.L., 254
Goodenough-Trepangnier, C., 328
Goodrich, G.L., 28
Gopalakrishnan, P., 335
Gosine, R.G., 13
Goss, K., 397
Grey, T.L., 82, 350
Gross, K., 166
Grott, R.L., 436
Gunderson, J., 338
Guthrie, C.L., 138
Haataja, S., 308
Hale, Jr., P.N., 295
Halpin, M.E., 417
Hamann, G., 160
Hammel, J., 16
Hansen, P.K., 174
Harkins, J.E., 38, 41
Hawkins, R., 300
Heine, K.S., 263
Heiner, D., 92
Henderson, K., 166
Hendriks, J.L., 248
Henry, K., 333
Hershberger, D.H., 216
Heyward, C., 300
Hickey, A.P., 227
Hiesterman, R., 179
Hillman, M., 21
Hinkens, J.D., 163
Hoffman, A.H., 33
Hoglund, E., 196
Honsinger, M.J., 196
Hopely, R.C., 417
Horowitz, D.M., 85, 317
Horstmann, H.M., 100
Hoy, M.G., 1
Hron, C., 430
Hussey, S.M., 266
Hyman, W.A., 222
Hyodo, A., 272
Inigo, R.M., 148, 151
Jacobs, J.L., 283
Jaffe, D.L., 28
Jaros, L.A., 10
Jasch, C., 344
Jensema, C.J., 41
Jercinovic, A., 277
Jones, T.J., 269
Jones, T., 13
Jones, M., 109
Jonsson, A., 23
Jordan, C., 391
Joyce, M., 379
Kanevsky, D., 335
Kangas, K.A., 260
Kashitani, L., 274
Kauzlarich, J.J., 143, 146, 234
Kelly, C., 367
Kirby, R.L., 356
Klabunde, C.R., 48
Klein, M., 115
Klemen, A., 280
Kline, B.R., 4
Ko, W.H., 411
Koenig, S.C., 133
Kohn, J., 24
Kolenc-Krajnik, A., 280
Korba, L., 251
Korres, E., 38
Kostraba, J.R., 333, 383
Kreiter, K.E., 344
Kummell, J., 376
Kuntzman, A.J., 292
Kushler, C.A., 207
Labuzzetta, J.W., 121, 131
Lacefiled, W.E., 58
LaCourse, J.R., 133
Laenger, C.J., 353
Lahm, E.A., 225
Lanciault, M.C.S., 298
Langton, A.J., 76, 79
LaRue, D.J., 414

Lash, M., 85
Lavanchy, C., 30
LeBlanc, M., 24
Lechelt, E.C., 326
Lee, J.H., 353
Lenker, J., 367
Levine, S.P., 10, 100
Limon, A., 176
Loepelmann, K.A., 326
Logan, L.K., 185
Logan, G.D., 243
Luebben, A.J., 171, 347
Lundman, M., 23
Majaess, G.G., 356
Malagodi, M., 399
Malzahn, D., 115
Marsden, R.J., 168
Marsolais, E.B., 283
Matheson, K., 358
McCoy, K.F., 97, 109, 112
McGillis, G.J., 168
McKinlay, A., 204
McNeal, D.R., 289
Meadows, P., 274, 286, 391, 397
Meher, B., 263
Meidenbauer, N.L., 72
Mifsud, M., 409
Miller, L., 274
Miller, G.E., 222
Milner, M., 157, 160, 308
Minson, A.A., 166
Moran, R., 361
Morris, C., 105
Morris, T., 118, 125
Morrow, K.R., 433
Mortola, P.J., 24
Muik, E.A., 370
Mulcahey, M.J., 394
Murphy, H.J., 230
Murray, I.R., 311
Nahamoo, D., 335
Nantais, T., 157
Naumann, S., 154, 361, 409
Negami, S., 272
Newell, A.F., 103, 105, 107, 311
Novak, M., 163
Nyberg, E.H., 112
O'Beirne, H., 157
Oda, S., 274
Oeth, R.B., 171
Olson, D., 358
Orpwood, R., 21
Parette, Jr., H.P., 219
Park, G., 251
Park, C.W., 148
Parnes, P., 160, 308
Patterson, R., 202
Pausch, R., 320
Pence, R., 151
Peng, A.C., 411
Pennington, C., 109
Poppenhagen, B., 358
Prior, S.D., 19
Puckett, F.D., 295
Pullin, G., 21
Rahman, T., 123
Raschke, U., 10
Ray, S., 94
Rebersek, S., 277, 280
Reger, S.I., 272
Rego, R., 303, 305
Reiss, K., 358
Repperger, D.W., 27
Reyes, E.T., 272
Ricketts, I.W., 103
Rodgers, M.M., 292, 402
Rohde, S., 323
Rosen, M.J., 128, 248, 328
Ryan, S.E., 361
Sabelman, E.E., 1, 364
Sabourin, C., 286
Salton, J.R., 430
Sauer, M., 341
Schauer, J., 163
Schnepf, G.W., 181
Schoenberg, A., 50
Schweitzer, J.R., 295
Scott, N.G., 64
Scott, D., 13
Scull, E.R., 269
Segner, S., 90
Shafik, K.T., 148
Shapcott, N., 367
Shein, F., 157, 160, 308
Sheldon, E.J., 185
Shively, R.A., 292
Siebens, A.A., 376
Silverman, C., 227
Skiba, J., 92
Slack, M., 361

Slattery, P.J., 243
Smith, B.T., 394
Smith, R.O., 67
Spaeth, D.M., 213
Spicer, P.J., 430
Stammers, C., 21
Stolov, W.C., 196
Strum, G.M., 97
Stuart, S., 112
Suddath, C.R., 381
Szeto, A.Y.J., 414
Tchang, F.V., 427
Teeter, J.O., 70
Tew, J.P., 257
Thacker, J.G., 143, 146, 237
Thrope, G.B., 70
Touras, N., 118
Trachtman, L.H., 190
Trahan, C.A., 263
Treviranus, J., 160, 308
Trimble, J., 118, 125
Triolo, R.J., 394
Trittin, P., 314
Troy, B.S., 427
Van der Loos, H.F.M., 16
VanBiervliet, A., 74, 219
Vanderheiden, G.C., 163, 187
Vanderheiden, K.R., 187
VanNote, D., 367
Villar, F., 388
Vittitoe, N.F., 381
Vodovnik, L., 277
Vogtle, L.K., 320
Waller, A., 107
Ward, J.T., 7
Warner, P.R., 19
Watanabe, K., 240
Waters, R., 274, 286, 391, 397
Wederich, C., 286, 391
Werner, P.C., 364
Westlake, E.M., 436
White, P.A., 136
Williams, N.S., 41, 425
Williams, P.A., 323
Williams, R.D., 320
Willkomm, T.M., 183
Winkler, F.W., 140
Winograd, C.H., 1
Wolff, A.B., 38
Wright, A.G., 103
Wyatt, C., 341, 383
Wylde, M.A., 7
Wynne, J.E., 269
Young, L.J., 347
Young, M., 409
Zachary, S.V., 402
Zeljic, V., 280
Zivec, T., 286
Zuber, D., 140

RESNA '91

14th Annual Conference

RESNA

Suite 700
1101 Connecticut Avenue, N.W.
Washington, D.C. 20036
(202) 857-1199 • Fax (202) 223-4579